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Corrosion investigation of a steam turbine after power generator failure onboard a vessel: A case study

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ABSTRACT

Steam turbines for power generation installed on vessels are designed to operate for over 30 years. However, there are some cases of untimely failures. In this paper, we are reporting a case of a deeply damaged turbogenerator, with several visible corrosion/erosion attacks, such as 'pit-shaped' defects, rust, and drains. While significantly widespread, they were almost only observed on the inlet steam flow side. Also, their extension and size were not such as to affect the integrity of the failed rotor, especially if we consider the size of its blades and discs. Some chemical elements not included in the alloy composition of the turbogenerator are detectable on the surface of the turbine components. Their presence could be due to passivation layers and/or material oxidation, in the case of oxygen, or, in the case of other elements detected in very low amounts and contained in the steam, to their deposition during standard turbine operations. However, turbogenerator storage conditions at the shipyard workshop before analysis might also be involved.

Based on our data, we would rule out that a damage such as detachment of all blades from the sixth disc in the intermediate-pressure stage was caused by material corrosion/erosion. This conclusion was further supported by reports by the crew on how the failure had occurred. Other turbogenerators similar to the one described in our paper are currently operating on vessels. Therefore, this paper can be useful to better manage steam turbines for power generation and prevent corrosion/erosion damage.

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1. Introduction

Steam turbines are the core of power plants, converting linear motion of high-temperature (HT) and high-pressure (HP) steam into rotary motion of the turbine shaft. As a matter of fact, as steam enters the turbine from the boiler, it flows through different pressure gradient stages from high-pressure (HP), to intermediate-pressure (IP), and low-pressure (LP), while generating mechanical motion [1]. All pressure stages, especially those where steam starts to become wet, are sensitive to impurities contained in the condensate being formed on the surface of turbine discs and blades. Chemical elements such as chloride, oxygen, and carbon dioxide can promote corrosion which in turn weakens disc and blade strength to alternating bending, thereby resulting in premature turbine failures and subsequent shutdown of power generators [2]. In addition, the drag of solid particles by the steam flow is another major problem during turbine operations. These foreign particles can either be deposited on the turbine

Abbreviations: HP, High-Pressure Stage; IP, Intermediate-Pressure Stage; LP, Low-Pressure Stage; SEM, Scanning Electron Microscope; EPMA-EDS, Electron Probe Micro Analyzer with Energy Dispersive Spectrometer

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trail and blades, causing wear and reducing turbine efficiency, or be hurled at high speed against the blade surfaces, promoting the formation of erosion pits in preferential areas [3]. More than 50% of previously described failures were related to fatigue, stress corrosion cracking, and corrosion fatigue [1]. Steam turbine rotors are among the most critical and highly stressed components in modern power plants. The consequences of a rotor failure are severe in terms of both safety and economic impact. For this reason, electric power utilities and manufacturers quantify and limit the risk of such failures using the concept of ‘rotor life’, namely the maximum number of service hours and hot and cold starts a rotor can undergo [4–6]. Several research works have shown that the low-pressure blades of steam turbines are generally more susceptible to failure than those in intermediate and high-pressure stages [7–10].

Steam turbines for power generation operating onboard vessels are usually designed to run for over 30 years. However, we are herewith reporting on an untimely failure of a 17-year-old turbine. The first inspection of the disassembled turbine showed that most of the damage had occurred in the IP stage, where all blades had come off the sixth disc. Several turbo generators similar to the one herein described are currently installed onboard vessels. We were not asked to perform a root cause analysis (RCA) and therefore to establish whether corrosion/erosion phenomena observed on the turbine after its disassembly following its failure were likely to have damaged the turbogenerator but, rather, to analyze any corrosion/erosion attacks on the turbine surface in order to determine their severity. Thus, by characterizing the type of corrosion/erosion detected on the turbine, we aimed to investigate its likely role in damage onset. In addition, our data could also be useful to figure out whether the extent of observed corrosion/erosion is likely to lead to turbine failure during the future life of a similar system, and whether some extraordinary maintenance works should rather be planned. For this reason, samples from blades and discs from all pressure stages in the turbine were analyzed.

2. Materials and methods

2.1. General information on the turbine system under study

As claimed by the manufacturer, the average turbine operation is about 8 kh/y with over 30-year durability. Main turbine operating parameters, such as power output, rotational speed, steam temperature, and pressure at inlet and outlet, are listed in Table 1. The maintenance plan provides for a general overhaul every 4–6 years with annual inspections. The boiler and feedwater are pre-treated and controlled to minimize the risk of corrosion damage and deposition problems, as well as efficiency or output loss. For the same reasons, the water-steam circuit should also be under continuous monitoring. The values given by the manufacturer for live steam condensate conductivity and composition are reported in Table 2. Furthermore, under project conditions, steam condensation begins (transition of overheated steam to saturated wet steam) at the IP stage, namely in the fifth rotor area (steam quality: 0.991).

The alloy composition used for building the turbine as reported by the manufacturer is: 28 Cr Mo Ni V 4.9 (SEW555 W nr.1.6985) steel for rotor, and X 22 Cr Mo V 12.1 DIN 17240 high-resistance stainless steel for blades.

2.2. Sample collection

Representative samples of damaged and intact turbogenerator parts were obtained from blades and discs. In order to limit material corruption caused by heating, workers at the shipyard cut out a large portion of each concerned disc (at least 15 × 15 cm),

Table 1
Main turbine operating parameters.

Maximum power output	1600 kW at 1800 rpm
Rotational frequency	183 Hz at 11,000 rpm
Setting of overspeed regulator:	
-Electronical	199.8 Hz at 11,990 rpm
-Mechanical	201.6 Hz at 12,100 rpm
First calculated critical frequency	98.2 Hz at 5892 rpm
Absolute inlet steam pressure	61 bar
Inlet steam temperature	510 °C
Steam outlet pressure	0.05/0.1 bar
Steam outlet temperature	33 °C
Lubricating oil pressure	1.5 bar
Oil flow rate of thrust bearing	2370 l/h
Oil flow rate of front load-bearing	278 l/h
Oil flow rate of rear load-bearing	278 l/h
Weights	
Turbine	5000 kg
Adaptor	2500 kg
Alternator	5000 kg
Lubrication system	1600 kg

The above values were given by turbogenerator's manufacturer.

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