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Failure analysis of a run-of-the-river hydroelectric power plant

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ABSTRACT

One of the challenges posed by hydraulic energy generation stems from the exploitation of hydrological resources that carry significant amounts of sediment that erodes the surfaces of turbines. This is the case for the Amaime hydroelectric plant, which is located in the western mountainous region of Colombia and was seriously affected by sediment after a brief period of operation. The main symptom indicating failure was a rise in the temperature of the bearings caused by an increase of almost two bars in the pressure between the cover on the side of the generator and the runner, which was caused by the wearing of the seal labyrinths. Inspections that were carried out after six months of operation indicated that there was a 300% increase in the clearance between the covers and the runner, which caused a higher axial thrust on the bearing. The inspections verified that severe wear had occurred on important elements of the turbine, such as the runner, guide vanes and turbine covers, which required major repairs to the two generation groups of the plant in less than 2 years, which is a much shorter time between repairs than is recommended by international standards. Analyses of the material, medium, particles and the worn surfaces demonstrated that the wear on the turbine was mainly due to erosion by hard particles, which was caused by the high sediment concentration and the low hardness of the material used to construct the turbine.

1. Introduction

A large portion of the hydroelectric energy generated in Colombia comes from small hydroelectric plants that operate as run-of-the-river plants, and many of these are affected by the high concentrations of particles in the rivers that feed them. One of these plants is the Amaime hydroelectric power plant, which began operation in January 2011 and has a generation capacity of 20 MW. However, 5 months after its operation began, its surfaces already exhibited wear damage, which led to increased temperatures in the driving bearings and average losses in the working efficiency of up to 30% [1]. Inspections verified that severe wear had occurred on the surfaces, which deteriorated the labyrinth seals and increased the flow of water towards the back side of the runner, which in turn increased the driving pressure by almost two bars. Because this wear also represents a significant loss of efficiency, which leads to economic losses in addition to the necessary repairs, the owners of the plant implemented several actions, including the monitoring of the sediment concentration. Preliminary calculations determined that a stoppage criterion of 2 ml/l was needed to avoid severe wear of the machines. This measure reduced the wear rate of the groups but also caused the plant's operations to stop for 548 h between May 2013 and December 2014.

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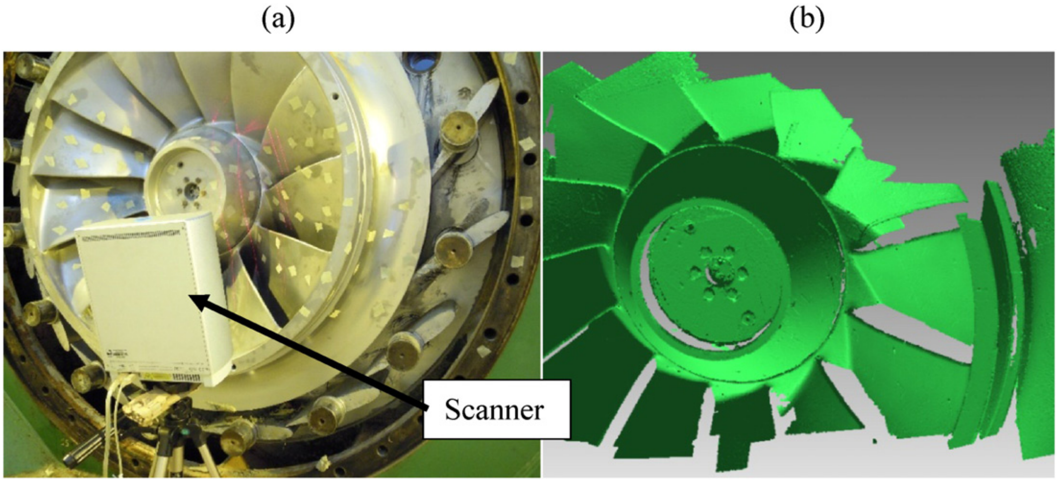

Fig. 1. (a) 3D data acquisition from the surfaces of interest on the turbine; (b) partial digital reconstruction of the runner surface.

Wear problems on this type of hydraulic machinery are common in mountainous regions of the Andes and the Himalayas, where soil erosion occurs as a result of weak geologic formations and strong precipitation over short periods of time [2]. For example, in the Cahua hydroelectric plant in Peru, there have been reports of advanced wear of elements such as guide vanes and runner. The wear was attributed to the high concentration of sediments and the hardness of the particles, which was approximately 3 times greater than the hardness of the material in the machinery [3]. A similar case occurred in the Himalayan region of India, where the stay and guide vanes, labyrinth seals and runner of the turbine were affected; in that case, the particles were quartz and feldspar, which have high indexes of hardness of 7 and 6 on the Mohs scale, respectively, and angular shapes that make them highly abrasive. Investigators also reported that the desander, which was designed to retain particles larger than 150 μm, was allowing 13% of those particles through, which, combined with 92% of the particles smaller than 150 μm that also passed through the desander, had the greatest effect on the wear on the turbine's components. The authors also determined that the significant amounts of wear led to a loss in efficiency of up to 4.97% in only 6 months [4]. Complete failures of the seal rings and buckets in Pelton turbines have been reported due to the operation of a plant with high sand concentrations, changes in the properties of the materials in localized regions and loads beyond the recommended operational limits of the plant [5].

This study characterizes the problem of wear on the turbines in the Amaime hydroelectric power plant, which is located in the central mountain range of the mountainous region of Colombia. We characterize the materials and the medium, estimate the wear rate and analyse the phenomena causing the wear based on visual inspections of the affected parts.

Table 1
Results of the chemical composition analysis.

Sample	Material	% elements										
		C	Si	Mn	P	S	Cr	Ni	Mo	Cu	Co	W
Runner	GX4CrNi 13-4	0.037	0.736	0.776	0.014	0.001	10.740	3.505	0.484	–	0.032	–
Hubcap and anti-wear rings	X20Cr13	0.220	0.256	0.707	0.009	0.004	11.076	0.644	0.134	0.053	0.011	0.010

Table 2
Hardness measurements.

Hardness [HV]	Anti-wear rings	Generator side Hubcap	Suction side Hubcap	Labyrinth seals	Runner
Mean	226.50	229.25	227.63	228.25	208.85
Standard deviation	2.87	2.33	2.00	2.82	30.15
Interval (95%)	1.92	1.56	1.34	1.89	18.22
Error	0.85%	0.68%	0.59%	0.83%	8.73%