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Hydro-abrasive erosion in Pelton buckets: Classification and field study

Anant Kr. Rai[a,*], Arun Kumar[a], Thomas Staubli[b]

[a] Alternate Hydro Energy Centre, IIT Roorkee, Roorkee, India
[b] Lucerne School of Engineering and Architecture, Fluid Mechanics and Hydro Machines, Switzerland

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ABSTRACT

In fragile mountainous regions, hydropower plant components face severe hydro-abrasive erosion, resulting in reduced efficiency, frequent interruptions in power generation and downtime during maintenance. In this study, the hydro-abrasive erosion is classified and measurement methodology is proposed for various erosion patterns in Pelton buckets. In Pelton buckets of a high head hydropower plant located in the Himalayas in India, the amount, pattern and depth of erosion were measured during the study period May-October 2015. The size, shape and concentration of the suspended sediment passing through the turbines were obtained from manual samples and with an online multi-frequency acoustic instrument.

In uncoated buckets, the average reduction of the splitter height and the abrasion in the cut-out portion were 3% and 5% of the bucket width respectively, whereas the maximum erosion depth of ripples in the curved zone was 1.5%. 73% of suspended sediment consisted of silt particles with median grain size (d_{50}) between 20 and 40 µm. With coefficient of variation 75%, 32% and 1% for concentration, d_{50} and shape respectively, 12,540 t of suspended sediment passed through each turbine unit during 3180 h of operation. This study seeks to facilitate the measurement of hydro-abrasive erosion in Pelton turbines and suspended sediment parameters.

1. Introduction

In geologically young mountains like the Andes and the Himalayas, most of the streams contain high suspended sediment concentration (SSC) during the rainy/monsoon seasons. The suspended sediment causes hydro-abrasive erosion in hydraulic turbines and other project components coming in direct contact with moving sediment laden water. The hydro-abrasive erosion poses challenges for smooth and efficient operation of existing hydropower plants (HPP) as well as for the development of new HPPs. In the present day, hydro-abrasive erosion (henceforth referred to as "erosion" for simplicity) has gained much needed attention as it causes the loss of power generation as well as expensive maintenance [1]. The loss of generation is due to reduced efficiencies of generating units due to profile changes of the turbine blades/buckets caused by erosion [2]. Run-of-river (ROR) plants face high erosion as they do not have storage options for settling and removing the suspended sediment. For ROR schemes with high heads, even small sediment particles cause high erosion, especially in Pelton turbines due to the high velocity. Though several researchers have identified parameters involved in the erosion of Pelton turbines such as suspended sediment concentration, size, shape, mineral contents, material composition, erosion velocity and duration of operation [3–5], the quantitative information about influence of these parameters is not fully known. Though the International Electrotechnical Commission (IEC) [6] provides an empirical model for calculation of erosion in hydro-turbines, model coefficients related to Pelton turbines are not provided due to lack of field studies.

In the laboratory, the erosion is usually measured with weight loss [7,8], thickness loss and surface roughness change [3], due to the ease of measurement of small sized test specimens. Rajkarnikar et al. [9] used paint to visualise erosion on small Francis blades in the laboratory. However, the measurement of erosion in hydro-turbines of actual HPP is challenging because of irregular curved profiles of turbine components, varying erosion thickness with ripples, non-availability of reference surfaces due to change of original profiles, and the large size of turbine components [3]. In actual HPPs, thickness reduction provides the quantity of erosion, which can be measured using templates and thickness gauges [4,10]. Bajracharya et al. [11] studied erosion in the 2-jet Pelton turbine of Chilime HPP (2 × 11 MW) in Nepal and related the erosion to the efficiency reduction of the turbine. The erosion of needles and nozzle rings was measured with a stylus probe apart from measuring suspended sediment with sieves and mineral analysis of manual samples in the laboratory. They found an erosion depth of 3.4 mm/year for needle and bucket, resulting in loss of 1.21% efficiency of turbine, caused by 80% hard mineral quartz. Boes [12] studied erosion in the 4-jet Pelton turbine of Dorferbach HPP (1 × 10 MW) in

* Corresponding author
E-mail address: anantkrai@gmail.com (A.K. Rai).

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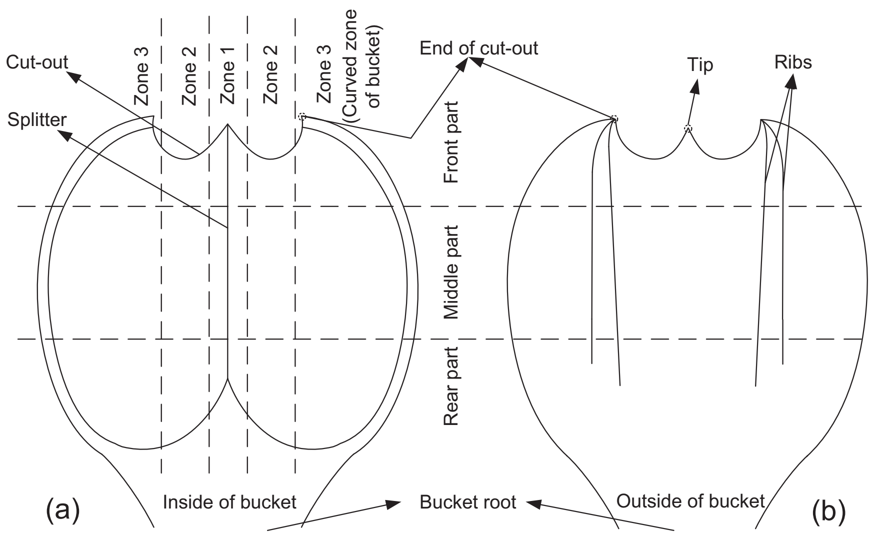

Fig. 1. Different zones and terminology used for (a) inside and (b) outside of a Pelton bucket.

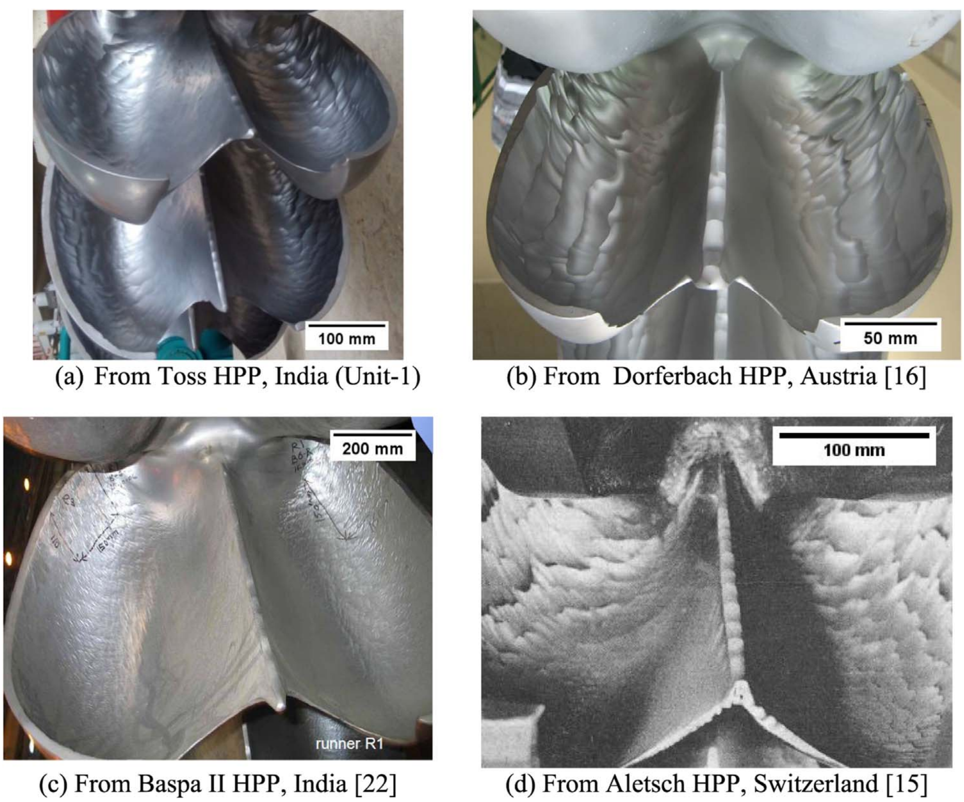

Fig. 2. Hydro-abrasive erosion in uncoated Pelton buckets.

Austria from May to October 2008 by (a) measuring the increase in splitter width (17 times for 3 Pelton runners) using templates and (b) measuring SSC and particle size distribution (PSD) continuously with an optical backscatter turbidimeter as well as a laser diffraction instrument along with manual pumped sampling. To forecast erosion and to assess the effect of counter measures, an erosion model was developed for the plant studied.

Recently, researchers applied imaging and video techniques to monitor erosion in turbine components to facilitate inspection without major dismantling, lesser inspection time and to provide offline image comparison [13,14]. Dahlhaug and Thapa [13] inspected Francis turbines in Jhimruk HPP (3 × 4 MW) in Nepal with a borescope to observe damages like holes and cut-offs. In some major erosion studies [4,11,14], researchers obtained and analysed the erosion from the difference of initial and final state of turbine components. Abgottspon et al. [14] measured erosion of coated Pelton buckets with an optical 3D-scanner from the year 2012–2014 in a 515 m high head Fieschertal HPP (2 × 32 MW) in Switzerland. The coating thickness distribution inside Pelton buckets was also measured using a thickness gauge based on magnetic induction. The SSC and PSD were measured continuously with turbidimeters, acoustic and laser diffraction instruments. During the whole study period, the splitter height reduced by 3–5 mm in 2012 only due to one major sediment event of 20 g/l SSC. The erosion in coated and uncoated buckets differs considerably and use of these modern techniques for uncoated Pelton buckets is rarely reported.

IEC [6] recommends the measurement of erosion thickness in uncoated Pelton buckets at minimum 5 points per half bucket and splitter width on top at 3 locations (front, middle and back) using templates. However, this methodology cannot quantify various erosion forms in Pelton buckets, especially in cut-out region. In this study, an attempt