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Iron-oxidising microbial biofilms as possible causes of increased friction coefficient in intermediate and lower guide vane bearing bushings at a hydroelectric powerplant in Brazil ☆

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Abstract

Increased coefficient of friction led to malfunction of many and destruction of some maintenance-free bushings of intermediate and lower guide vane bearings at a hydroelectric power plant in Brazil. Analysis of surfaces of failed bushings revealed the presence of three types of deposits. The contact zones between bushings and the guide vane axis were covered with a thin black graphite film. The remaining bushing surface was covered by a mix of yellow-red coloured deposits, which contained a large proportion of iron-oxide-rich microbial biofilms, and green-coloured deposits, which consisted largely of copper oxides. Biofilms sampled from both the inside and the outside of the bearings contained 75% iron oxides by weight. The iron oxide deposits produced by these biofilms were identified as the primary cause of increased friction resistance between the bushing surface and the guide vane axis. Iron deposition within biofilms was made possible by the action of iron-reducing bacteria in the anaerobic zone of the reservoir immediately in front of the turbine intakes. These bacteria enriched the anoxic reservoir water with Fe(II) and the relatively small oxygen concentrations in turbine feedwater prevented the complete oxidation of Fe(II) in the penstock. Water-proofing of the bearing seals would prevent water penetration into the bearings and biofilm formation on the bushing surfaces and thus avoid the type of failure observed at this plant.

Keywords: Iron-oxidising bacteria; Iron-reducing bacteria; Microbial biofilms; Guide vane bearing; Hydroelectric power plant; Water turbine; Maintenance-free bushing

1. Introduction

The hydroelectric power plant industry relies heavily on the use of maintenance-free bearings in guide vanes. These bearings reduce maintenance costs considerably and do not impact water quality, as grease-based bushings do (Jones et al., 1999; Hilp, 2004; Koch et al., 2005). The self-lubricating bearings used can be made of a bimetal material comprised of a stainless steel support and a layer of sintered bronze, which contains solid lubricant (small particles of graphite, Rohatgi et al., 1992). These self-lubricating bearings are then assembled by interference fit in a bronze container and fixing pins are used to ensure the fixation of the self-lubricating bearing inside the bronze container. This design is well proven in the hydroelectric power plant industry. However, at a hydroelectric power plant located in central Brazil, a continuous increase of the coefficient of friction between the bushing and the guide vane shaft led to bushing failure after less than 4 years of operation. The fixing pins were sheared and the self-lubricating bushings rotated horizontally and/or vertically inside the bronze container. Some of the bushings were even partially forced out of their containers. This type of failure was observed in guide vane bearings from all three

☆Scientific relevance of the paper: This paper identifies iron-oxide depositing microbial biofilms as the primary cause of the increased friction drag and the subsequent failure of self-lubricating guide vane bushings in a hydroelectric powerplant in Brazil. To our knowledge this is the first such report on this issue, which seems to affect quite a number of hydroelectric powerplants around the world.

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Francis turbines operated at the plant. This investigation was undertaken to identify the cause of failure of the maintenance-free bushings and to propose ways to remediate the problem.

2. Materials and methods

2.1. Chemicals and glassware preparation

All solutions were prepared with distiled water, unless stated otherwise. Pure water, where applicable, was obtained from a Prima 8 BP USF Elga water purification unit (USFilter, UK). All chemicals used in experiments were of reagent grade or better, unless stated otherwise: ethanol (Malinckrodt-Baker, Xalostoc, Mexico); sulphuric acid, nitric acid and NaCl (Labsynth, Brazil); 4′, 6-diamidino-2-phenylindole (DAPI, Molecular Probes, Eugene, OR, USA); glycerol, KOH, extran detergent, tryptic soy broth (TSB) and tris-hydroxymethylaminomethane (Merck, Darmstadt, Germany); gelatine (Acumedia, Baltimore, MD, USA); $KCrSO_4$ (Vetec, Brazil); R2A (Difco, Detroit, USA) and urea (Ridel de Haehn, Seelze, Germany). Glassware was cleaned with a solution containing an alkaline detergent (extran 5% m/v in pure water, Merck, Brazil), which was removed with tapwater before immersion of glassware in a sulfonitric acid bath (Schneider et al., 2005a).

2.2. Collection of water samples

Samples for analysis of total organic carbon (TOC), total inorganic carbon and growth potential of oligotrophic microbes (GPOM) were stored in sterile 40 mL borosilicate vials (I-CHEM, New Castle, DE, USA) sealed with Teflon-coated screwcaps. Samples for GPOM determination were filtered in the field through sterile 0.2 μm membranes, which had been washed with 100 mL pure water prior to sterilisation (Millex, Millipore, Brasil). The first 10 mL of permeate were discarded to avoid sample contamination with organics from the filters. Samples for analysis of cations and anions were stored in 125 mL screw-cap plastic vials (Fischer Scientific, Hampton, NH, USA), which were washed with a detergent solution (10%v/v extran in pure water) and rinsed first with tap water and then 3 × with pure water and dried at room temperature. All water samples were transferred immediately after collection into a Styrofoam box with ice, which was used for all sample transfers. Samples were stored in refrigerators in the hotel or in the laboratory. Water samples were collected in the intake channel at depths of 42 m (lower end of the penstock intake), 30 m (about 3 m below the upper end of the penstock intake) and 17 m (about 10 m above the upper end of the penstock intake, representing probably the upper limit of water drawn into the turbines). Reservoir water samples from predetermined depths were collected with a van Dorn sampler.

2.3. Collection of samples of the self-lubricating bearings

Bearings were removed with great care by power plant staff to avoid contamination of the inner surface of the bearings. The bushings were separated from the bearings in a workshop located inside the power plant and areas of interest for analysis were cut manually from the bearing with a steel saw, taking great care not to damage or contaminate the sample surfaces. The self-lubricating layer was separated from the stainless steel support by manually flexing the base back and forth, holding both ends with pliers. The bearing surface samples were fixed on the bottom of Petri dishes (bearing surface side up) with adhesive tape on both ends. The lids of the Petri dishes were fixed with adhesive tape to ensure contaminant-free transfer of the samples to the laboratory.

2.4. Microbiological analysis and electron miroscopy

Total and viable counts as well as electron microscopy were performed as described in Schneider et al. (2005a).

2.5. Elemental analysis

Dried samples (approximately 1 g) mechanically homogenised (Spex CertiPrep Inc., USA) for 5 min in a plastic beaker were deposited on a boric acid disk and compressed at 20 MPa for 10 s prior to analysis by X-ray fluorescence (RIX 3000, Rigaku Co., Japan). The disk was prepared by compressing 1.5 g of boric acid in a hydraulic press (HAG12, Herzog, Osnabrück, Germany) at a pressure of 100 MPa for 10 s.

2.6. Determination of the GPOM

The GPOM was analysed as described in Schneider et al. (2005b).

2.7. TOC and dissolved organic carbon (DOC)

TOC and DOC were analysed using the NPOC routine of the high TOC C + N analyser (Elementar, Hanau, Germany) as described by Schneider et al. (2005b).

2.8. Dry weight and organic matter content

Dry weight and organic matter content were determined as described in Schneider et al. (2005a).

2.9. Ion chromatography

Cations and anions in water samples were analysed with a 761 Compact IC (Metrohm Ltd., Herisau, Switzerland) ion chromatograph. Calibration curves were established using the following calibration standards: multi-component anion standard (AccuStandard, Inc., New Haven, CT, USA) and IsoSol cation standards (Pensalab, São Paulo, Brazil). Samples were injected into the ion chromatograph through a 0.22 μm disposable filter (Millipore, São Paulo, Brazil). Eluents (3.5 mM sodium bicarbonate and 1.0 mM sodium carbonate in 1 L pure water for anions; 5 mM tartaric acid, 1 mM dipicolinic acid and 24 mM boric acid in 1 L pure water for cations) were degassed for 1 h prior to use. Anions were separated with a Metrosep Anion Dual 2 column (Metrohm Ltd., Herisau, Switzerland) using an eluent flux of 0.8 mL/min whilst a Metrosep C1 (Metrohm Ltd., Herisau, Switzerland) column was used for separation of cations with an eluent flux of 1 mL/min. Analytical separation columns were protected with a Metrosep RP Guard precolumn (Metrohm Ltd., Herisau, Switzerland).

2.10. Determination of reduced iron (FEII) and total iron, manganese and sulphite

Colorimetric kits were used for determination of reduced and total iron (DLH – 2000 DEL LAB, DELFINI, Araraquara, São Paulo, Brazil), manganese (K-6502 kit, Chemetrics, Calverton, USA) and sulphite (K-9510 kit, Chemetrics, Calverton, USA), always following the manufacturer instructions. Manganese, reduced iron and sulphite concentrations were measured in the field immediately after sample collection.

3. Results and discussion

3.1. Visual inspection of bushings

The surfaces of the chamber below the lower vane guide bearings were covered by a several millimetre thick brown, mucuous and slimy biofilm (Fig. 1A), parts of which sloughed off when the water from the inside was drained. Surface fouling in the access chamber was most severe below the lower bearing 6 and less intense in the chambers