AKOSOMBO HYDRO-ELECTRIC POWER STATION GENERATOR THRUST BEARING UPGRADE CASE STUDY

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1.0 ABSTRACT

The six generating units at Akosombo Hydroelectric Power Station of the Volta River Authority in Ghana were commissioned in 1965 with an original installed capacity of 912MW. Having operated successfully for 30 years past inception, a major overhaul was carried out to upgrade and modernize the plant for an additional 25 to 30 years of trouble- free operation. Total installed capacity after the upgrade is now 1020MW.

High performance and more efficient turbine runners were installed as part of the major overhaul, obviously increasing thrust load on the generator thrust bearings. Hitherto, the generator thrust bearings had operated reliably without any significant problems. Following installation of the new turbine, significant increase in thrust bearing operating temperatures (from an average of 76 Deg C to 86 Deg C) was observed, and indicative of increased thrust load on the generating units.

This situation became more serious when a rare and unique form of recurring cavitation damages also became evident on the thrust bearing pads. This phenomenon, which progressed steadily on the various individual thrust bearing pads, necessitated yearly inspection to check and repair the thrust pads by scraping off loose babbitt and re-polishing the surfaces with scouring pads. In other instances, the set of thrust pads had to be replaced because they had virtually failed.

Several consultations and attempts were made by the Original Equipment Manufacturer (OEM) to provide an appropriate and permanent solution to this rather unusual phenomenon. Bearing optimization recommended by the OEM was implemented but did not resolve the cavitation damage on the thrust pads, even though the operating temperatures were reduced.

The Volta River Authority contracted Hydro Tech Inc of Canada, who designed a thrust bearing to match operation of the new replacement turbine runner at Akosombo. This solution featured new and modified split thrust bearing rotating rings and superior PTFE

thrust pads having higher load carrying capacity than traditional babbitt bearings.

2.0 INTRODUCTION

The Akosombo Hydroelectric Power Station of the Volta River Authority, Ghana, has six generating units initially installed with a total capacity of 912MW. The first four units were commissioned in 1965 with a total capacity of 588MW and two further units in 1972, also with total capacity of 324MW.

In the 30 years since inception, operations at the Station had been very reliable. A technical audit was carried out with the objective of modernizing the plant and looking for another 25 – 30 years of trouble free operations

A major overhaul of the generators and turbines therefore commenced in 1999, which amongst other upgrades, featured installation of new replacement turbine runners to improve efficiencies and increase power. This upgrade was successful and finally increased the generating station's efficiency, resulting in a total installed capacity of **1020MW** (i.e. 170MW X 6 units).

As a result of the more efficient and high performance turbine runners at Akosombo Generating Station, the new turbine also increased hydraulic thrust experienced at the same flows as the previous runner. This condition contributed to ***rare and unique recurring cavitation damages*** on the generator thrust bearings.

Following the upgrade, thrust bearing operating temperatures increased from 76 Deg C to 86 Deg C. The OEM recommended bearing optimization by re-arrangement of the thrust bearing support springs. Even though the high temperatures were reduced to an average of 82 Deg C, a residual problem of recurring cavitation damages to the thrust bearing pads emerged.

After several pursuits of a permanent solution, VRA contracted Hydro Tech Inc of Canada, who designed a new thrust bearing featuring a modified highly-toleranced split rotating ring, keyed and bolted together to form one complete ring (with zero gaps at the splits). This would solve the immediate cavitation problem, however, the bearing would still be overloaded. It was decided to improve load capacity of the bearing pads by replacing them with superior PTFE thrust bearing pads having higher load capacity over the traditional babbitt bearings.

Installation of the new thrust bearing assembly was successfully carried out on Units 2 and 5 at Akosombo in November 2009 and, as expected, thrust bearing operating temperature reduction in the order of 7 to 8 Deg C was achieved (from 83 Deg C to 76 Deg C). Since then the thrust bearing temperatures are being monitored and there are all indications of good operations.

3.0 THRUST BEARING PROBLEM

Before installation of the new replacement runners, initial concerns were raised about possibility of increased thrust load associated with the new runners and design capacity of the existing thrust bearings to match any increase in thrust load.

Unit # 3, which was first to be overhauled at the Akosombo Generating Station, operated with an average thrust bearing temperature of **76 Deg C** prior to the re-turbining in October 1999. During commissioning in July 2000, after the retrofit, a significant increase in temperature was observed at an average figure of **86 Deg C.**

This situation confirmed increased thrust load on the generating unit, associated with installation of the new replacement turbine runner at Akosombo and this raised a concern with the client, VRA, and the Contractor, as the Original Equipment Manufacturer (OEM), also happened to be the leading partner in the consortium of contractors on the retrofit project at Akosombo.

Unit 3 thrust bearings failed after almost 20 months in service during April 2002. Even though there were other circumstances involved, additional concerns were raised about the increased temperature and thrust load and the ability of the existing thrust bearing to safely support this new load.

The OEM therefore carried out a bearing optimization study, at its own cost, and recommended a revised thrust bearing support spring arrangement to improve performance of the existing bearing. This was implemented by removing eleven support springs (mainly from the leading edge end), which resulted in a total of 40 support springs as compared to the original 51 springs per bearing pad.

OEM reports indicated an increase in the oil film thickness associated with the modified spring arrangement, therefore suggesting a more reliable bearing operation with reduced temperature. Temperature reductions were observed with the revised spring configuration on the Akosombo Units and the average thrust bearing operating temperatures came down to **82 Deg C.** However, some thrust pad replacements resulted in either lower or higher operating temperatures above this average, depending on which type of thrust pad had been installed originally.

The old Akosombo thrust pad design, with its dovetail bond was observed to generally run at higher temperatures than the new design having a straight bond type. Damaged Unit 6 thrust pads were changed from the straight bonded type to re-babitted old-design dovetail type in 2006, resulting in increased operating temperatures of 81/82 Deg C to 83/84 Deg C. Similarly, the old-design dovetail-type thrust pads were replaced on Unit 5 in July 2005 to the straight bonded type.

The spring optimization definitely reduced thrust bearing operating temperatures; nonetheless, the emergence of a rather rapidly recurring cavitation damage phenomenon became obvious on the thrust pad surfaces. This pitting effect was normally concentrated within, and around, the High Pressure Oil Injection (HPOI) groove ring, towards the trailing end.

There are few cases of cavitation on thrust bearing pads. A design flaw must exist to allow cavitation to manifest itself when caused by a sudden pressure drop. In this particular case, the highest measured average bearing pressure is approximately 4.07 Mpa; however, this 4.07 Mpa is an average pressure. There also exist higher and lower pressures on the surface of the bearing. Generally, a higher load area is located in the middle of the bearing pad surface toward the trailing edge, close to where the High Pressure Oil Lift (HPOL) ports are. The HPOL port is where the most significant pressure drop occurs due to the change in oil film thickness and/or pressure (step in the babbitted surface and gap between the thrust bearing runner plate segments). With the increased thrust, the oil film between the Babbitt thrust bearing pads and thrust bearing runner plate has decreased, while the average pressure has augmented. This increased the pressure drop at the thrust bearing runner plate split, as well as increasing its subsequent effect on the Babbitt due to close proximity, resulting in the thrust bearing pads showing signs of cavitation pitting (Photo 1).

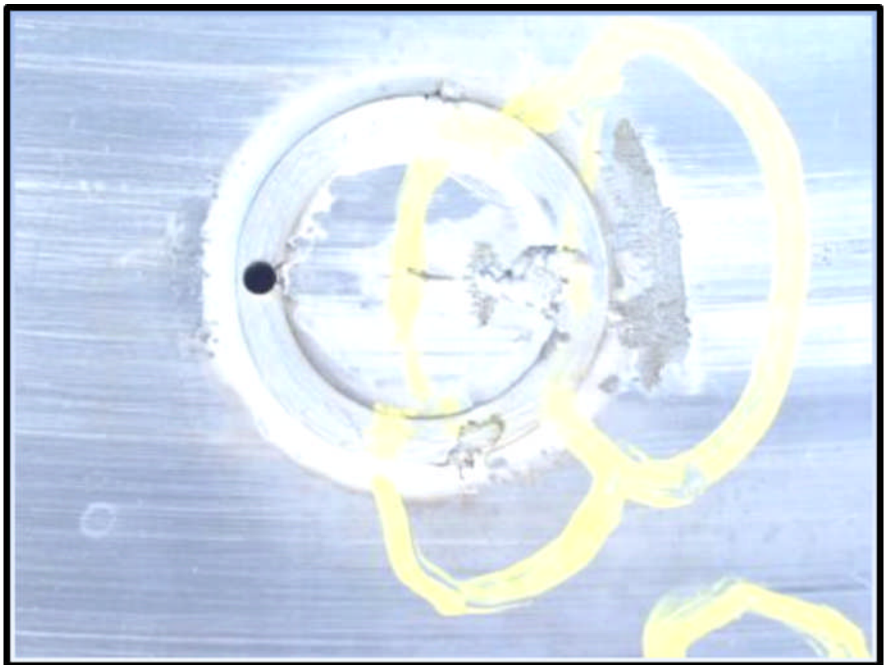

Photo 1
Old Babbitt Bearing Pads With Cavitation

Photo 2
Old Runner Plate With Gap Between Segments

There was also evidence of fatigue failure of the Babbitt surfaces, likely due to thermal effects, a condition known as “thermal ratcheting”. Thermal ratchet is caused by temperature changes on the bearing surface causing the Babbitt bearing pad to act as a bi-metal strip slightly bending the bearing pad causing a crowning. This is caused by the Babbitt expanding and contracting at a different coefficient of expansion to steel, and the surface of the bearing pad being hotter than the steel backing plate to which the Babbitt is bonded (the thicker the Babbitt, the stronger the thermal ratcheting effect that occurs) (Photo 3).

Photo 3
Cracked Babbitt

These unusual damages on the bearing pads became a greater concern to the client and its Contractors as cavitation and thermal ratcheting progressed steadily on the pads. The Contractor experimented with several modifications by machining different tapers and shapes within the HPOL groove ring, but the problem still persisted. Eventually it became obvious that initial concerns raised about the ability of the existing bearings to safely support increased thrust load associated with the new replacement runners were indeed valid.

The client, VRA, in consultations with Hatch Energy, consultants on the retrofit project, met with the OEM for a permanent solution to the Akosombo generator thrust bearing problem. The OEM's preferred solution was to install a new one-piece rotating ring, an approach which involved complete removal of the generator rotor. Considering the prolonged outage time involved with this approach, and the fact that the increased thrust load might still be above the safe load carrying capacity of the existing Babbitt thrust pads, VRA did not accept this solution.

After several pursuits of a permanent solution VRA finally contracted Hydro Tech Inc (a Canadian mechanical services company having extensive experience with thrust bearing retrofits), to modify and upgrade the Akosombo generator thrust bearing assembly in consideration of the recurring thrust bearing cavitation problem.

These problems were fundamentally attributed to the increased hydraulic thrust load of the new replacement turbine runner; however the original bearing was already susceptible to cavitation due to gaps in the runner plate quadrants. Prior to the turbine upgrade, there was at least one incident where cavitation was discovered on a bearing pad. At the time of discovery, the cavitation was considered to be porosity in the Babbitt. No further investigation was conducted at this time due to the area being small (approximately .75 inches in diameter).

4.0 Thrust Bearing Solution

Objectives of the Akosombo generator thrust bearing retrofit were to address the following issues:

- Increased thrust load of new replacement runners considered to be above the safe load limit of the existing thrust bearings.
- Solve the design flaw which was causing the cavitation on the thrust pad surfaces.
- Lower the operating temperatures

Increasing Thrust Load

Actual thrust loads on the individual generating units were measured as part of preliminary activities surrounding the bearing upgrade project, to inform the design of the new PTFE thrust pads. The thrust recorded at head water values were as high as

4.07MPa at a headwater elevation of 247FT above sea level (Maximum Headwater Level at Akosombo is 278FT above sea level). The actual maximum thrust loading increases as the Headwater level rises. Full head pond thrust measurements could not be measured as the head pond does not completely fill each year. The results once again were indicative that total thrust operating on the units was above the safe limit of Babbitt bearings.

Superior PTFE bearing pads with higher load capacity were installed to replace the traditional Babbitt bearings, which could not adequately match the increased thrust load of the new turbine runners. The new PTFE thrust pads for Akosombo feature compound tapers at the leading edge to facilitate oil flow and wedge formation, as well as pad eccentricity to permit higher specific load capacity. Using the PTFE bearing pads also allowed elimination of the HPOL system removing another potential source for cavitation.

Photo 4

New PTFE Bearing Pads

The solution provided by Hydro Tech Inc to address gaps at the splits of the existing rotating rings was a modified design of highly-toleranced segmented rotating rings, which are keyed and bolted together to ensure zero gaps at the splits. This new design would eliminate sudden pressure fluctuations caused by the splits. This type of joining was achieved during installation. The splits were lapped (stoned) to completely eliminate any sharp ends, eventually forming a one-piece thrust bearing rotating ring which was bolted to the thrust block.

The new thrust bearing runner plate acts as a solid one-piece ring providing constant pressure on the bearing pads over its entire surface. The bearing pad no longer experiences pressure fluctuations from the four quadrant slits that originally relieved pressure from maximum PSI to 0 four times per revolution.

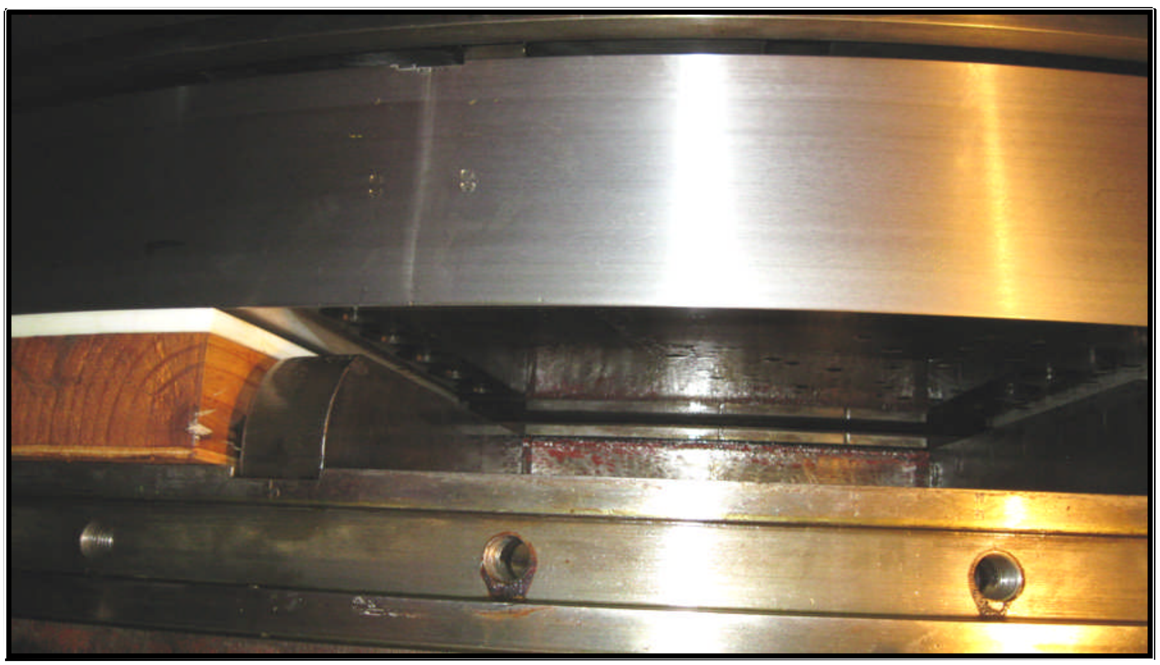

Photo 5
New Runner Plate Tightly Bolted Together

Lowering the Operating Temperature

With the increased capacity of the bearing pads, and pressure fluctuations caused by the runner plate repair, the bearing was able to operate more efficiently. The PTFE bearing has one fifth the coefficient of friction, preventing excess heating of the thrust oil. This allows the thrust bearing temperature to lower with no additional cooling.

5.0 Results

The new thrust bearing installation on Units 2 and 5 at Akosombo Generating Station has been very successful and all indicated problems which resulted in higher operating temperatures have been resolved. Temperature reductions of the order 7- 8 Deg C have been achieved from 83 Deg C to 76 Deg C.

The bearing pads were inspected after several months of running time; the bearing pads appeared to be in good condition.

Special thanks to the following participants.

Bearing designer, Hydro Tech Inc and its design team; the entire technical staff and trades people of Akosombo Generating Station; the PTFE bearing pad design by EnEnergo of Russia; Horst Mielke of Hatch Energy; Kjell Nyqvist of North American PTFE; John Sanderson and crew of Canadian Babbitt Bearing