SELF LUBRICATING BEARINGS FOR WATER TURBINES

By Rui Riyo Ueda, Adelino Sussumo Serizawa and Alex Ricardo Ferrer de Andrade, CESP, Brazil and Paulo Pereira, FM Deva, Germany

ABSTRACT

This paper describes CESP – Companhia Energética de São Paulo experience and learnings obtained during the turbines modernization program which is being executed at Jupia Power Station, 14 x 141 MW Kaplan turbines.

In the maintenance of its 6 hydroelectric power plants with total installed capacity of 7,455.30 MW, CESP - Companhia Energética de São Paulo has adopted criterias and procedures which provide better safety for the energy production systems in a sustainable manner, following the company concerns with the social and environmental impacts of its business.

We highlight the turbines modernization program with the application of maintenance solutions / actions with investment in special materials and techniques which is enabling us to implement improvements to eliminate the equipment weak points, providing the elimination of the equipment faults, defects and operational restrictions.

Among the several implemented improvements, we highlight the use of self lubricating bearings containing bronze and graphite in the general maintenance of HPP Jupiã Kaplan turbines, as follows:

a) Guide Vane Bearings

The original bearings were made of grease lubricated bronze with the seal installed only on the upper guide vane bearing.

With the introduction of self-lubricating bearings which has higher load capacity and therefore can operate with smaller sliding contact area, it was possible to install a better and more appropriate seal without affecting the bearing function and lifetime. The use of self lubricating bearings allowed us to eliminate the use of grease lubrication thus avoiding the possibility of problems with the environment related to water contamination.

b) Kaplan runner hub

We decided to also implement the self-lubricating bearings solution containing bronze and graphite lubricant in the runner hub assembly replacing the old traditional bronze bearings achieving the following results:

• More efficient lubrication of the bearing/ shaft system as the the oil inside of the runner does not provide an appropriate lubrication mainly due to the low angular movements of the runner blades;
• Wear of sliding components practically reduced to zero, thus eliminating any 
spendings with repairs
• Expectation that these components lifetime increase at least 50% compared to 
bronze
• Besides the above mentioned benefits, we highlight:
  • The importance given to Business Sustainability by eliminating the use of oil /
grease and centralized lubrication in the turbine;
  • The implementation of this maintenance program associated with several other 
  improvements introduced in the generating units, allow CESP to get the Brazilian 
electric sector regulatory agencies to disregard the downtime for maintenance in 
the calculation of operational performance indicators of the Company.

Although none of the 7 refurbished turbines have been disassembled for inspection yet, 
so far their performance is meeting our expectation and we do not notice any evidences 
of premature wear like oil leakage and increase of clearances in bearing assemblies of 
the the kaplan blades and in guide vane of the distributor mechanism. The experience 
shows that all refurbished turbines are now much more reliable than before the 
refurbishment job was done.

1 INTRODUCTION

The basic philosophy for programming and defining the frequency of maintenance jobs 
is specified in the maintenance instructions of CESP. The parameters considered for 
evaluation of each equipment and installation are: results of tests, examinations, 
inspections, performance, operation system, number of operations, environmental 
conditions, year of manufacture and available time for operation.

Normally the schedule of preventive maintenance is done within the recommended 
periodicity, but taking into consideration the specific characteristics of each plant and its 
generating units, the equipment conservation status, especially their operational 
conditions, the results of previous inspections and predictive tests. For this CESP has a 
maintenance management, where each generating unit is treated as an individual 
production unit. They are included in the annual and multi-annual machine maintenance 
programs under the responsibility of the Maintenance Engineering Department - GM and 
included in the Work Program of CESP Generation Division.

CESP generation park is currently comprised of six (6) hydroelectric power plants with 
total installed capacity of 7,400 MW, distributed as follows:

• HPP Ilha Solteira: 20 generating units with total capacity of 3.440,0 MW;
• HPP Três Irmãos: 5 generating units with total capacity of 1.292,0 MW;
• HPP Eng. Souza Dias (Jupiã): 14 generating units with total capacity of 1.551,2 MW;
• HPP Eng. Sérgio Motta (Porto Primavera): 14 generating units with total capacity of 
  1.814,4 MW;
• HPP Paraibuna: 2 generating units with total capacity of 85,0 MW;
• HPP Jaguari: 2 generating units with total capacity of 27.6 MW.

We highlight the General Periodic Preventive Maintenance (MPPG) which is being done at HPP Eng Souza Dias (Jupiá) as part of the maintenance policy adopted by CESP to increase the availability and operational reliability of its generating units. This is a large maintenance job in turbines with more complex design characteristics which involve the complete disassembly of the machine, maintenance, improvements and repair of components and assembly.

The largest preventive maintenance job is scheduled to be done between 160,000 and 240,000 hours of operation, when the generating unit will be completely dismantled.

This maintenance is done in at least one generating unit per year at HPP Eng Souza Dias (Jupiá), where we highlight the turbines modernization program with the application of maintenance solutions / actions with investment in special materials and techniques which is enabling us to implement improvements to eliminate the equipment weak points, providing the elimination of the equipment faults, defects and operational restrictions.

2 ENG. SOUZA DIAS HYDROELECTRIC POWER PLANT (JUPIÁ)

The Engenheiro Souza Dias Hydroelectric Power Plant (Jupiá), located in the Parana River between the cities Castilho (SP) and Três Lagoas (MS), was completely built with Brazilian technology and started operation in 1969. It has total installed capacity of 1551.2 MW, with 14 generating units and two turbine / generator groups for auxiliary service (installed capacity of 4,750 kW each group).

The Jupiá reservoir area has 330 km² and a 5495 meters long dam. In addition, the plant has a ship lock which allows the navigation on Paraná river and integration to Tiete Parana waterway.

Picture 1 – View of HPP Jupiá

Picture 2 – View of powerhouse
2.1 Turbine Characteristics

- Type: vertical kaplan;
- Manufacturer: Riva (units 1, 5, 7, 11 and 12), Asgen (2, 4, 6, 8, 10, 13 and 14) and Escher Wyss (3 and 9);
- Maximum power output: 110,000 kW;
- Head (max power output): 22.10 m;
- Water Flow (max power output): 515 m³/s;
- Direction of rotation: clockwise;
- Rated speed: 78.3 rpm;
- Rotor Diameter: 8,400 mm;
- Discharge ring diameter: 8190 mm;
- Spiral case diameter: 8480 mm;
- Runner hub total height: 5166 mm;
- Total weight of + runner hub + blades + blades trunnion: 279.5 tons;
- Number of runner blades: 5

![Picture 3 – Kaplan turbine detail](image)

2.2 Generating Unit General Periodic Preventive Maintenance

The HPP Eng Souza Dias (Jupiá) generating units general periodic preventive maintenance (MPPG) basically consists of the repair of worn parts of the Kaplan turbine, generator maintenance, implementation of improvements in the shaft seal, distributor mechanism and Kaplan runner hub, as well as modernization of mechanical equipment. In order to execute this general maintenance it is necessary to complete disassemble the generating unit, to have some parts sent to the factory for machining jobs and implementation of several improvement projects with application of self-lubricating bearings.
2.2.1 Design improvement to eliminate water infiltration through the guide vane bearings (24 units)

No matter if the guide vane bearings are made of bronze or selflubricating material, it is lifetime is dependent among other factors on operating without the presence of contaminants.

In the original design the guide vane bearings were made of bronze with grease lubrication and the seal was installed only on the upper bearing, therefore the intermediate and lower bearings were exposed to the presence of water.

Besides contaminating the grease with solid materials (sand), the presence of water can also cause corrosion on the guide vane trunnion which are factors that can affect the performance and lifetime of the bearing.

At the time of the introduction of the selflubricating material, consisting of a foil of PTFE (Teflon), in the HPP Jupiá turbines, the first thing to do was to install rubber seals in the intermediate bearing to prevent water from entering the bearing system.

However, only after the introduction of new selflubricating bearings made of sintered bronze + graphite (Type DEVA BM) to replace the PTFE foils, it was possible to introduce a technically more appropriate seal. This was possible because the new selflubricating material has a higher load capacity which allowed to work with a smaller sliding surface, ie, the height of the working surface of the bearings was reduced and therefore allowed enough space to adapt the new seal without affecting the function of the bearing.

This improvement consisted of applying a seal with "U" profile because of its easy adaptation and installation in the bearing assembly, and for having proven performance in similar applications. The seal material specified is nitrile rubber with a hardness of 85 Shore-A.

As the performance and lifetime of the new bearings installed in the guide vanes is related to the efficiency of the seal, then It is very important that the seal performs its function, ie, preventing the passage of water and protecting the bearing from abrasive materials.

To perform this job is necessary to disassemble the guide vanes in order to send it to the machine shop. Therefore, this job can only be done during a MPPG (general periodic preventive maintenance) job.

The complete service performed on the guide vanes consists of the following tasks:

a) Guide vanes trunnion
   - Inspection and dimensional check of the three trunnion bearing journals (Ø280 x 200,5 mm, Ø340 x 325mm and Ø320 x 340mm);
• Pre-weld machining, 5 mm radius of each journal;
• Fill with welding material using stainless steel AISI 410, keeping the surface hardness of 280-300 Brinell;
• Grinding to achieve the final trunnion dimensions according to design tolerance and roughness.
• Machining of a chanfer on the top of $\varnothing$340 to facilitate the installation of the bearing with assembled seal;
• Adjustment and finishing of transition radius;
• Inspection and dimensional and geometric control.

Note: The maximum tolerance of concentricity between the trunnion journals is 0.05mm. If the Contractor opts for welding system, they must submit its process to CESP inspection and approval because it must be of continuous type (Automatic application) in order to have successful result of services.

Pictures 4 and 5 – Detail of guide vane trunnion welding process

Pictures 6 and 7 – Detail of guide vane trunnion journals machining
b) Lower guide vane bearings

- Consists of machining the existing bronze bearings for the installation of the self-lubricating bearings eliminating the greasing tubes and closing the holes.
- Machining the inner diameter (5 mm in radius x 160mm) of the existing bearing to be the container of self-lubricating bearing.

Note: The tolerances for machining and assembly procedures must comply with the specifications of the self-lubricating bearing manufacturer.

c) Intermediate and upper guide vane bearings

- Consists of machining the existing bronze bearings for the installation of the self-lubricating bearings eliminating the greasing tubes and closing the holes.
- Machining the inner diameter (5 mm in radius) of the existing bearing to be the container of self-lubricating bearing and to install the seal.
- Adaptation of the seal, development of device to facilitate assembly or modification of the seal.

Note: The tolerances for machining and assembly procedures must comply with the specifications of the self-lubricating bearing manufacturer. The contractor must provide seals and other components required for adaptation of the seal.

Note: With the introduction of self-lubricating material it was possible to eliminate the grease lubrication system.
2.2.2 Design for adaptation of self lubricating material in turbine runner hub guide bearings and shoes.

During the 90s with the concern regarding the high costs of maintenance and turbine components lifetime, such as the servomotor and the distributor mechanism, it was introduced a solution consisting of implementing an adaptation of PTFE (Teflon), a thermoplastic with excellent mechanical properties and commercially available in the market. The result had very positive technical and economical impact, especially in the application as a sealing ring of distributor servomotor.

Considering this positive aspect, we decided to introduce DEVA BM, a technically more noble selflubricating material, to be used in the turbine runner hub assembly with satisfactory performance.

This self lubricating material in the shape of bearings and shoes consists of a bimetal structure i.e., support in stainless steel and sliding layer in bronze with small particles of graphite solid lubricant homogenously distributed in its structure.

In the case of shoes and the flanges of the bronze bearings, the selflubricating segments are fixed with countersunk screws. It has a cross section for spring effect, ie, when mounting the interference is achieved by tangential force (see Figure 1).

![Figure 1](image.png)

Figure 1 – fixation of the support plate with selflubricating material on the bronze shoe

Self-lubricating materials were installed in the following components in the turbine runner hub:
- Bottom inner bearing of guide shaft;
- Upper outer bearing of guide shaft;
- Runner hub servomotor cylinder bearing;
- Runner hub servomotor guide shoes;
- linkages;
- Lifting eyebolt bearings;
- Shoes
- Runner hub inner blade trunnion bearings
- Runner hub outer blade trunnion bearings

The following services were necessary to be done in order to adapt the selflubricating material:
a) **Bottom inner bearing of guide shaft**
- Consists of machining the existing bronze bearings and the installation of the selflubricating bearings;
- Machining of the existing bronze bearing inner diameter (3 mm in radius) for the installation of the selflubricating bearing;
- Adaptation of the seal

b) **Upper outer bearing of guide shaft**
- Consists of machining the existing bronze bearings and the installation of the selflubricating bearings;
- Machining of the existing bronze bearing inner diameter (5 mm in radius) for the installation of the selflubricating bearing;
- The inner diameter must be according to the journal final dimension
- Adaptation of the seal

c) **Servomotor cover (1 piece) and bottom inner bearing of guide shaft (Ø430/400x300 mm)**
- Consists of machining the existing bronze bearings and the installation of the selflubricating bearings;
- Center the cover on the lathe by the diameter 1960 h6 and perform dimensional check;
- Machining of the bronze bearing inner diameter (5 mm in radius) for the installation of the selflubricating bearing;

d) **Adaptation of selflubricating material in the servomotor guide shoes**
- Consists of machining the runner hub servomotor guide shoes and installing them.

e) **Lifting eyebolts**
- Grinding of the side faces of eye bolts (05 units), where the inner and outer rods work;
- Inspection and dimensional check of the eyebolt side faces (parallelism, flatness and eccentricity);
- Grinding of the side faces to restore surface is recovered with maximum removal of 0.5mm per side and design tolerance;
- Machining of existing bronze bearing of the eye bolts and installation of the self-lubricating bearings;
- Machining the inner diameter (3 mm in radius) for adaptation and self-lubricating bushing assembly.

f) **Linkages bearings (5 pieces)**
- Consists of machining the existing bronze bearings and the installation of the selflubricating bearings;
- Machining of the existing bronze bearing inner diameter (3 mm in radius) for the installation of the selflubricating bearing;
g) **Runner hub blades (5 pieces)**

- Grinding of runner hub blade trunnions;
- Dimensional check of the blade trunnion journals $\varnothing$ 500 x 308.5 mm and $\varnothing$ 800 x 316 mm;
- Analysis and definition of the values of the diameters of the final grinding, based on the smallest pair of values found;
- Centering on the lathe and grinding the diameters in accordance with design tolerances;
- Dimensional control and check of the paralelism of the related trunnions;
- Rehabilitation of the sealing mating surface on the blade trunnion;
- Flange $\varnothing$1280 H7 x 53 mm, inside and $\varnothing$1431 h6 x 104.1 mm;
- Pre-machining of worn parts;
- Filling in with welding material of martensitic stainless steel AISI 410;
- Machining according to dimensions and tolerances and indicated in the design;
- Seal mating surface $\varnothing$1280 H7;
- Pre-machining of worn parts;
- Filling in with welding material of martensitic stainless steel AISI 410;
- Machining according to dimensions and tolerances and indicated in the design.

h) **Kaplan runner hub outer bearing (5 pieces)**

- Consists of grinding of the existing bronze bearing;
- Machining of the bronze bearing inner diameter (5 mm in radius) for the installation of the self lubricating bearing;
- Machining of the flange outer surface (5mm deep) for installation of the self lubricating segments;
- The inner diameter will have the same dimension of the trunnion;
- Installation of 05 sets of runner hub blades radial outer self lubricating bearings in the existing bronze bearing;
- Installation of 05 sets of runner hub blades axial outer self lubricating bearings on the flange of existing bronze bearing.

i) **Kaplan runner hub inner bearing (5 pieces)**

- Consists of machining the existing bronze bearings and the installation of the self lubricating bearings;
- Machining of the existing bronze bearing inner diameter (5 mm in radius) for the installation of the self lubricating bearing;
- Installation of 05 sets of runner hub blades radial inner self lubricating bearings in the existing bronze bearing;
2.2.3 Project for adaptation of selflubricating material in the distributor mechanism

The load and frequency control system of a hydraulic turbine is equipped with an electronic control system where the system frequency can be monitored (from 59.98 to 60.02). The generating unit tries to keep this under control by operating within this frequency range and therefore by adjusting the electrical, electronic, and hydraulic mechanical controls continuously it corrects and adjusts to the desired system frequency.

Thus, the turbine is actuated through the hydraulic circuit by a linear movement of the hydraulic cylinder rod which transmits the movement to the regulating ring. As the regulating ring is connected to the guide vanes by the linkages, it actuates all the guide vanes on a synchronized way and therefore allows passage of water through the turbine. Depending on the degree of the guide vane opening, more or less water will flow through the turbine therefore controlling the speed in the turbine as a response to the load frequency in the related generating unit.

In the original design of our turbines, the regulating ring assembly had an axial thrust bronze block fixed to its bottom surface which slid in a channel full of oil. We decided to eliminate the oil and, to do this, it was necessary to implement the use of self lubricating materials and PTFE foils solution was adopted initially.
The following figure shows the situation of the original design:

Figure 2 – shows the original design situation. At dimension “H” is possible to see the lubrication channel (1), the axial thrust bronze block (2) and the guide roller (3).

Figure 3 - the axial thrust bronze block (1) situation after the modification and the guide roller (2)
The following picture shows the axial thrust block:

Picture 12 - Regulating ring with the axial thrust block and without PTFE foil/bronze
Picture 13 – thrust block without PTFE foil/bronze

The following pictures show the roller with grease lubrication and the insertion of the bearing made of Deva metal:

Picture 14 – Guide roller with lubrication
Picture 15 – Roller with selflubricating bearing

Self-lubricating materials were installed in the following components:

- Bearings of the connection of regulating ring to linkages;
- Bearings of the connection of linkages to guide vane levers;
- Bearings of the regulating ring pulleys;
- Servomotor rod bearings;
• Sliding segments of the regulating ring.

For adaptation of selflubricating materials in the distributor mechanism, the following services were performed:
• The existing distributor mechanism bronze bearings were machined in the inner diameter to be transformed in containers for the self-lubricating bearings;
• The shaft journals were refurbished to allow working without grease, i.e., some received a layer of martensitic stainless steel weld and others had a stainless steel sleeve installed;
• Manufacturing of the sliding supports of the regulating ring (6 pieces);
• Manufacture of six self lubricating axial segments;
• Machining of bearings connecting the regulating ring and linkages, installation of the self lubricating bearings and elimination of lubrication tubes and closing existing lubrication holes.
• Manufacture news pins in AISI 410 martensitic stainless steel for all linkages and regulating ring connection;
• Installation of 48 self lubricating bearings;
• Machining of the existing bronze bearing of the regulating ring pulleys (12 pieces), installation of carbon steel bearing, machining for the installation of selflubricating bearing and installation of selflubricating material axial segment;
• Machining the inner diameter of the existing bronze bearing to install the selflubricating bearings and axial segments;
• Installation of 8 bearings for rollers with diameter of 80 mm;
• Installation of 8 bearings (4 pairs of length 60 mm) for rollers with diameter 100mm;
• Installation of 8 selflubricating segments for rollers with diameter of 82mm;
• Installation of 4 pieces with diameter of 110mm.

3 CONCLUSION

After having already modernized 7 Kaplan turbines at HPP Eng Souza Dias (Jupiá), the results achieved are in accordance with our expectation and CESP policy to increase the availability and operational reliability of its generating units.

The solution adopted to implement the use of devabm selflubricating material replacing grease lubricated bearings and PTFE foil has proven to be a good decision as it has provided better safety for the energy production in a sustainable manner following the company concerns with the social and environmental aspects of its business.

The main advantages of devabm selflubricating material when compared to PTFE foil are its higher load capacity as PTFE foils can be deformed when submitted to high loads and its longer lifetime.
With the implementation of this improvement several benefits are expected to be achieved like the increase of lifetime of these bearings, elimination of costs related to machining of worn parts, and elimination of costs with grease and oil which were used in the distributor mechanism.

Besides the mentioned economical benefits, we highlight the priority given to the protection of the environment by eliminating the use of grease and oil which is already a standard practice in Hydro Generation worldwide.

Although none of the 7 refurbished turbines have been disassembled for inspection yet, their performance is meeting our expectation and we do not notice any evidences of premature wear like oil leakage and increase of clearances in bearing assemblies of the Kaplan runner hub and in the guide vanes of the distributor mechanism. The experience shows that all refurbished turbines are now much more reliable than before the refurbishment job was done.

Authors


Adelino Sussumo Serizawa: Mechanical Engineer degree from the Universidade Estadual de São Paulo – UNESP Guaratinguetá / Brazil in 1975. He is currently supervisor of mechanical maintenance at Jupiá Power Plant. He works for CESP - Companhia Energética de São Paulo since 1978.

Alex Ricardo Ferrer de Andrade: Electrical Engineer graduated at Escola Federal de Engenharia Itajubá – Brazil in 1987. He is currently Division Manager of electromechanical maintenance engineering at CESP - Companhia Energética de Sao Paulo where he works since 1988.

Paulo Pereira (Speaker): Mechanical engineer graduated at Universidade Catolica de Petropolis – Brazil in 1984. He joined Deva do Brasil in 1996 as sales manager for automotive business and later became responsible for the Industrial and hydro business. In October 2004, he moved to Germany where he is currently working for Federal Mogul Deva GmbH as Hydro Application Manager.