Creating a Grease-Free Environment At Dinorwig Power Station

By William O. Moss

The 1,728-MW Dinorwig Pumped-Storage Power Station in the United Kingdom undergoes many modes changes per day in providing system stability and reserve for the national grid in England and Wales. In doing so, its greased bronze turbine bearings sustain severe wear. After conducting extensive tests, operator First Hydro decided to install grease-free bearings, with the help of an innovative in-situ *milling machine.*

An original specification for the six-unit, 1,728-MW Dinorwig Pumped-Storage Power Station in North Wales called for the facility to be capable of 40 mode changes per day for at least a full 12-month period without any scheduled maintenance. Since its commissioning in 1982, Dinorwig has fulfilled the requirement.

However, owing to the particularly onerous operating conditions, some of the grease-lubricated bronze turbine bearings have sustained severe wear and have had to be replaced as often as every two years. This, together with the operational and maintenance costs and adverse environmental effects of frequent pumping of grease, led to a review of grease-free alternatives for these bearings.

Bill Moss is mechanical engineering manager for First Hydro Company, which manages and operates the Dinorwig Pumped-Storage Power Station in the United Kingdom.

Playing a special role

Dinorwig's role in protecting the national grid for England and Wales was adopted during the 1970s when the Central Electricity Generating Board, then the primary electric sector regulatory agency, selected the concept of hydroelectric pumped storage as the best option for frequency regulation and reserve.

Overall electricity demand was rapidly increasing. The trend involved construction of 500- to 660-MW baseload thermal units, with the possibility of building thermal units twice that size. The concern was that if one or two units failed, the grid would have to be reinforced within 10 to 15 seconds or the power system would collapse. That is where the Dinorwig Pumped-Storage Station comes into the picture.

Dinorwig features fast-opening spherical valves that permit early opening of the guide vanes during starting or loading from a "spinning-in-air" condition. Dinorwig's six main rotary inlet valves — one for each unit — are among the fastest in the world, designed to open in about five seconds and close in 20 seconds. Pump-turbine units are kept spinning-in-air, synchronized to the grid, ready to provide a rapid reserve of electricity in the event of a plant failure or sudden peaks in demand. This standby mode gives Dinorwig the fastest response time of any pumped-storage power station in the world. In approximately 12 seconds, the output of Dinorwig can be ramped from zero to 1,320 MW.

The site chosen for the power station was the Dinorwig slate quarry that operated for more than 160 years, up until World War II. The station was built in a man-made cavern inside the mountain, Elidir Mawr, on the boundary of the Snowdonia National Park. Each of the six reversible Francis-type pump-turbine units can produce up to 288 MW of electricity at 18 KV, producing a total of 1,728 MW. On-site transformers step up the voltage to 400 KV. The electricity leaves the site through underground cables and connects to the national grid at a substation in Pentir 9.7 kilometers away.

Alternatives to greased bearings

As a result of providing rapid frequency stabilization and reserve power, Dinorwig's grease-lubricated bronze turbine bearings sustain continual wear. In the mid-1990s, First Hydro decided to explore using grease-free bearings.

In exploring the greaseless bearings available on the market, First Hydro engineers discovered that none of the existing tests of available materials was applicable to Dinorwig because of the plant's unusually demanding operating conditions — conditions that would have been difficult to recreate in the laboratory. As a result, First Hydro engineers decided to test bearing materials *in-situ*, in order to achieve accurate and directly useful results.

Guide vane bearings were chosen for the tests. The upper bearing of this assembly is exposed to the most severe conditions and shows the worst wear rates of all the grease-lubricated bearings on the turbines. There are 72 such bearings (24 upper, 24 intermediate, and 24 bottom) on each of the six turbines. They, therefore, offered many prospective locations for testing a large number of the available greaseless bearings.

In 1996, First Hydro offered several greaseless bearing manufacturers the opportunity to participate in the tests by supplying their self-lubricating bearings for the guide vane application. Each manufacturer supplied two identical bearings for each position, sized to fit the existing housings. The tolerances and clearances were agreed upon between First Hydro and engineers from each of the manufacturers.

To monitor wear rates, proximity probes were mounted on one bearing from each pair. Each pair was separated in order to find out if there was any position effect. The bearings were removed and inspected as opportunities permitted, and, if performing well, were reinstalled for continued testing.

A total of three years was spent on the testing program. The effort included researching, testing, monitoring, and developing alternative materials. Then, in 1999, First Hydro made decisions regarding the use of materials for specific applications.

Orkot TXM bearings were chosen to replace the original grease-lubricated bronze guide vane upper and intermediate bearings and the regulating ring servomotor connecting rod link bushings. Lubron AQ30 bearings were chosen to replace the original guide vane bottom bearing, the regulating ring servomotor connecting rod spherical bearing, and the regulating ring bearing.

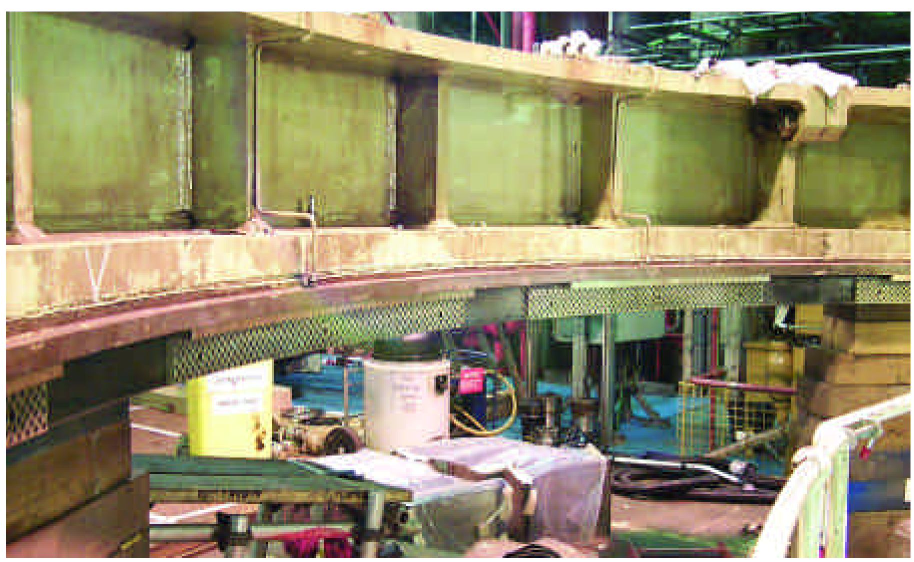
Focus on replacement of the regulating ring bearing

In replacing the regulating ring bearing, First Hydro engineers discovered a difficult and potentially expensive problem. The new bear-ing that was selected is an aluminum bronze bearing with AQ30 PTFE (polytetrafluoroethylene) solid lubricant inserts. To ensure a long life for a self-lubricating bearing, the counter-face must have adequate hardness, a good surface finish, and no corrosive products. Consequently, the existing carbon steel track, which was scratched and corroded, was not suitable.

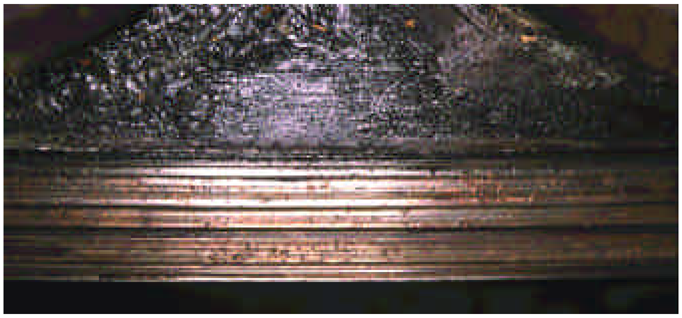
Burgess Hatem, a Senior First Hydro mechanical engineer, designed a new bearing arrangement. This design incorporated a stainless steel liner to be attached to the existing worn track. The regulating ring bearing is "L-shaped," and so has a horizontal and a vertical part. It has a rotational movement of only 34 degrees at a relatively slow speed. The pressure-velocity value for the bearing was calculated, yielding the conclusion that a full 360-degree bearing was not required. Instead, a segmented bearing design would be adequate.

The bearing itself is made up of 24 segments (12 horizontal and 12 vertical). The stainless steel liner is in 20 segments (12 horizontal and eight vertical). The segments of the bearing and liner are carefully positioned so that the bearing segments do move off of the stainless steel liners on rotation.

In order to accommodate the thickness of the stainless steel liners and to repair the damage found on the existing track, the top cover vertical and horizontal bearing track required machining. Normally, machining this track would require stripping down the unit,



This photograph shows a new self-lubricating Lubron AQ30 regulating ring bearing in place at the Dinorwig power station in the United Kingdom, the last step in First Hydro Company's goal to create a completely grease-free turbine.



Existing tracks for regulating ring bearings at the 1,728-MW Dinorwig Pumped-Storage Power Station in the United Kingdom were scratched and corroded, as shown in the photograph on the left. To ensure a long life for replacement self-lubricating bearings, plant operator First Hydro Company designed a stainless steel liner to be attached to the track, as shown in the photograph on the right, that provided a hard, smooth surface with no corrosive activity.

which would result in weeks of downtime and lost generation. This would require that the regulating ring bearing be split and removed. Then, the 5.5-meter-diameter, 100-ton top cover would need to be removed and taken to a workshop for machining. The cost due to manpower and loss of productivity would be huge.

If this machining could be done without removing the top cover, downtime and manpower could be dramatically reduced. In the search for such an *in-situ* machining device, First Hydro Company approached Furmanite International Ltd of the United Kingdom, a specialist in on-site machining.

Innovations in on-site machining

First Hydro's previous experience with Furmanite included a similar *in-situ* machining problem on the bottom cover at Dinorwig. To carry out that work, Furmanite had adapted a device it already had designed — the Circular Self-Leveling Milling Machine. The machine makes use of a sophisticated control system that adjusts the machining plane to follow a predetermined reference plane. First Hydro asked Furmanite about the feasibility of further adapting the device to machine the top cover.

A split-bearing sleeve, shown above, was designed by First Hydro Company and contractor Furmanite to help guide a milling machine as it rotated around the main turbine shafts during a bearing replacement project at the 1,728-MW Dinorwig Pumped-Storage Power Station.

Extensive development work followed. First Hydro supplied the requirements, while Furmanite adapted the machine to the application. The main adaptation was to assemble and rotate the machine around the turbine's main shaft. For this, a special split-bearing sleeve was designed, along with a clocking arm for setting the sleeve up concentrically with the bearing track. Of major importance was the flatness of the bearing track, but this was easily achieved with the milling machine's self-leveling technology and a specially designed split datum ring. The datum ring was pre-set using Furmanite's precision scanning laser system to give very high accuracy.

In order to minimize the risk of problems once on-site at Dinorwig, the adapted machine was tested and final adjustments were made on a full-sized mock-up of the shaft and bearing track at Furmanite's workshop. Furmanite demonstrated the machine for First Hydro engineers, then submitted a full risk assessment and method statement to First Hydro for review before arriving on-site.

Grease-free at last!

In 1999, the grease-lubricated bronze bearing on Unit 6 was replaced by the Lubron AQ30 self-lubricating segmented bearing. Furmanite machined the bearing track (horizontal and vertical) using the specially developed milling machine, removing approximately 3 millimeters of material before fitting the stainless steel liner segments.

This was the last step to a grease-free turbine. The work was successfully completed and the process — including set-up, machining, bearing and liner segment fitting, and de-rigging — took only nine days, with crews working 24 hours a day.

The vertical bearing track diameter was measured using a precision circumference tape. The flatness of the horizontal track was measured using the precision scanning laser system, and found to be within an acceptable 0.15 millimeter of the flatness required. On recommissioning the unit, numerous checks were made on the regulating ring bearing. All was well. The new bearing segments ran smoothly on the new stainless steel liners.

The future is bright!

Now, in 2001, five of the pump-turbine units at Dinorwig have undergone the bearing replacement procedure and are totally grease-free. Work on the sixth and final unit is scheduled for 2002.

The move toward grease-free units has aided First Hydro in its pursuit and retainment of ISO 14001 certification (International Standard for Environmental Management) for the Dinorwig Power Station. The absence of grease also has greatly improved the immediate working environment around each generating unit, eliminated the risk of grease ingress into the lake water, and saved on the cost of grease and grease dispensing equipment.

In the long term, the self-lubricating bearings will provide First Hydro with very substantial cost savings owing to the extended service life, which is at least three times that of the original grease-lubricated bearings, thus extending the time between routine maintenance and reducing the annual expenditure on replacement bearings. ▲

Mr. Moss may be contacted at First Hydro Company, Dinorwig Pumped-Storage Power Station, Llanberis, Gwynedd, North Wales LL55 4TY United Kingdom; (44) 1286-873213; Fax: (44) 1286-873252; E-mail: mossb@fhc.co.uk.

Reference:

Moss, W.O, and B. Hatem, "Testing Greaseless Bearings in Service," *HRW*, March 2000, pages 8-10.