ENVIRONMENTALLY ACCEPTABLE ALTERNATIVES TO WICKET GATE BUSHING LUBRICANTS

BY

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Introduction

Grease in the tailrace of powerplants is an environmental concern. Since the primary source of this grease is washout from wicket gate bushings, the Hydraulics Branch, Denver office, is conducting a study to test food grade greases and self-lubricating bushings. The greases and bushings will be evaluated on the basis of toxicity, mechanical properties, and water quality to determine the most viable, environmentally safe alternatives to the greases currently being used.

In addition, Dennis Christenson, Hungry Horse project superintendant, who has been the frontrunner in implementing these tests in order to preserve the environment, is currently conducting field tests with Husk-itt's Ultra Lube food grade grease. The Husk-itt grease was installed in one generator unit in June of 1992 and thus far has caused no problems.

Test Setup and Procedure

The wicket gate design for the test apparatus was modeled after a prototype wicket gate at the Mt Elbert powerplant in Leadville Colorado. Figure 1 shows the Mt Elbert wicket gate configuration. Each gate rotates 22 degrees from fully open to fully closed position at which point the gates seat against one another. The model shown in figure 2 represents one of these gates on a 1:4 scale enclosed in a rectangular conduit designed to allow a full 22 degree gate rotation. The model will supply a flow scaled according to the amount of flow through one wicket gate.

A motor driven operator will be attached to the shear lever arm shown in Figure 2. The operator will cycle the gate continuously on a 20 second, 4 degree stroke - with a 7 second pause between each cycle. In addition a full 22 degree stroke will be executed three times per equivalent prototype day. This schedule will represent a gate operated on automatic generation control which is the most severe duty cycle experienced by a wicket gate.

The tests will begin using a grease that is typical of the greases currently being used. In this case the grease will be Texaco's Multipak EP2. This will serve as a baseline for comparison for all test cases. The food grade greases scheduled for testing are:

SWEPCO's food machinery grease 115
Husk-itt's Ultra-Lube
Lubrication Engineers 4024 (H1)

The self-lubricating bushings to be tested are Thordon's SXL and Lubron's AQ100 bushings. Each grease or bushing will run through four test cases using a combination of two different pressures and flow rates. Each test case will run for a 48 hour test period which is equivalent to one month prototype time.

The following information will be gathered from each test run:

1. Torque will be measured by strain gauges mounted to the wicket gate shaft as shown in Figure 2.

2. Bushing wear will be determined by visual inspections and by bushing weight before and after each test run.

3. Water quality and washout characteristics will be determined from water samples gathered above and below the gate, as well as visual observations. In addition, toxicity tests have been performed on each grease by our Environmental Sciences group. Once these results have been interpreted we will make a relative comparison on this basis as well.

The tests described above were designed specifically to test food grade greases over a limited test period and therefore may not be a good indicator of the effectiveness or ineffectiveness of the self-lubricating bushings tested. In addition, much of the information supplied by manufacturers (based on rotating applications) becomes irrelevant due to the oscillating nature of wicket gate applications where the coefficient of static friction becomes significant. Therefore additional information on self-lubricating bushings is presented in Appendices A and B. Appendix A summarizes information from a report issued by Powertech Inc. who was commissioned by BC Hydro to design and implement tests specifically designed for greaseless bushings. Appendix B is a copy of a report issued by the Hydraulic Machinery Section, Denver Office.

Discussion

Several questions have arisen in determining the effectiveness of food grade greases and self-lubricating bushings. The following are a few of those concerns:

1. Can self-lubricating bushings be relied on for extended periods of time without maintenance or will contaminated water conditions lead to galling and eventual failure of this type of bushing? Greased bushings have a life span of about 30 years. Sand and silt is regularly purged by the process of daily greasing. The possible shorter life span of self-lubricating bushings needs to be examined.

2. Do the food grade greases have a Timken rating sufficient for the loads experienced by wicket gate bushings and will self-lubricating bushings withstand these same loads? High loads are experienced during load rejection and during gate squeeze in synchronous condensing mode. These limits need to be better defined.

3. Will pumpability or line clogging present a problem with food grade greases? This problem was solved at Hungry Horse when Husk-itt added mineral oil to it's Ultra Lube product. Pumpability should be tested before installing this type of grease.

4. Are food grade greases non-toxic and biodegradable? These definitions are not yet well defined. On one hand there are no known toxicity problems, such as harm to plantlife or fish, with the greases currently being used. On the other hand many greases, including some food grade greases, contain metal additives that may eventually seek their way into the food chain even though organic (biodegradable) or other processes have broken the greases down into their constituent components. Clearer definitions are needed.

5. Can manufacturer's recommended clearances for self-lubricating bushings provide the tolerances needed for certain lubricating materials which swell when subjected to wet conditions? The manufacturer's recommended clearances need to accurately account for this swelling action.

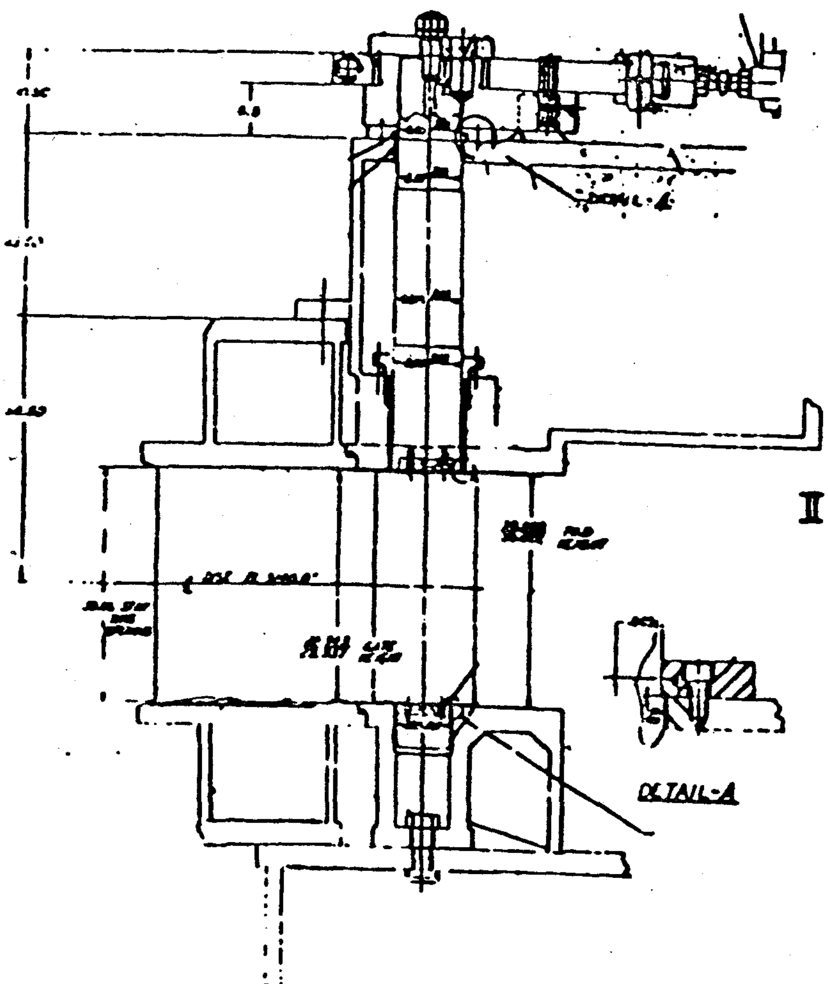
We will attempt to answer these questions throughout the course of this study.

An independent test on self-lubricating bushings is currently being commissioned by Ontario Hydro. We hope to get the results of this test program when it is completed. Additionally, a survey regarding the effectiveness of self-lubricating bushings is being conducted by the Canadian Electrical Association and should be out by the end of the year. This should be a good source of information regarding the effectiveness of self lubricating bushings. Many Canadian and European communities are in the process of replacing all of their greased bushings with self-lubricating bushings. However, since many of these plants have only installed these bushings in recent years it may be many years before we truly know the effectiveness of self-lubricating bushings.

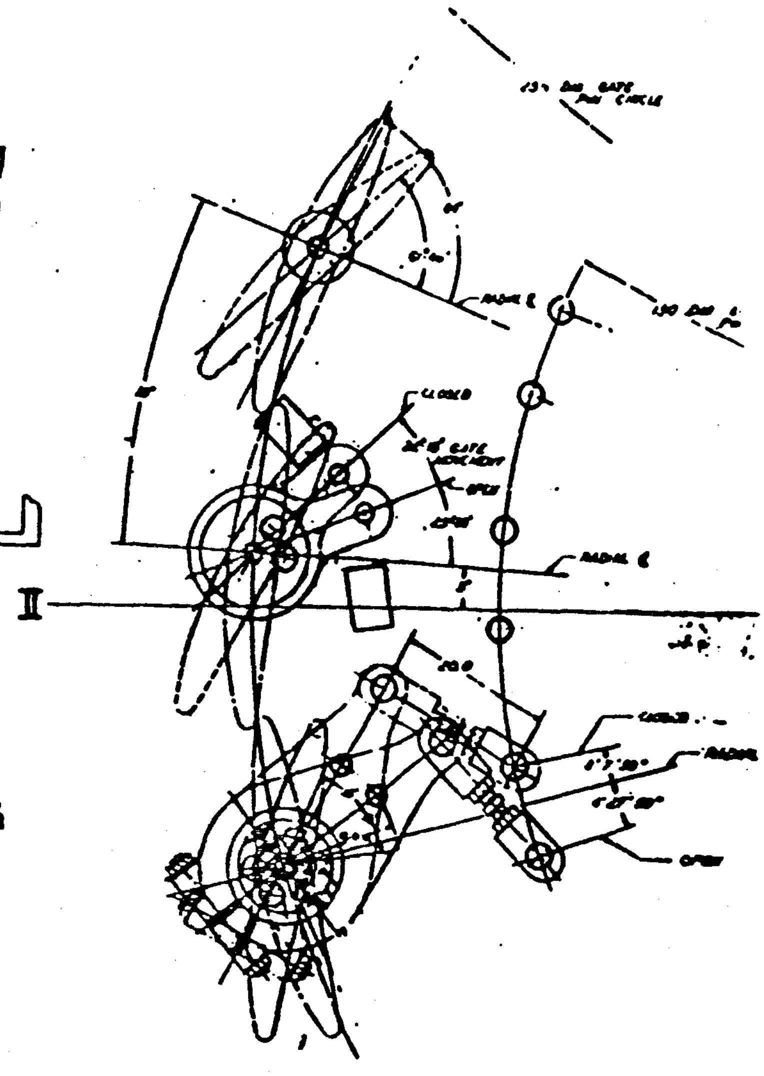
Conclusions

Once we have gathered and evaluated all test data, as well as information obtained from other available sources, we will make appropriate recommendations regarding environmentally safe alternatives to current greasing methods.

MT ELBERT WICKET GATE DESIGN



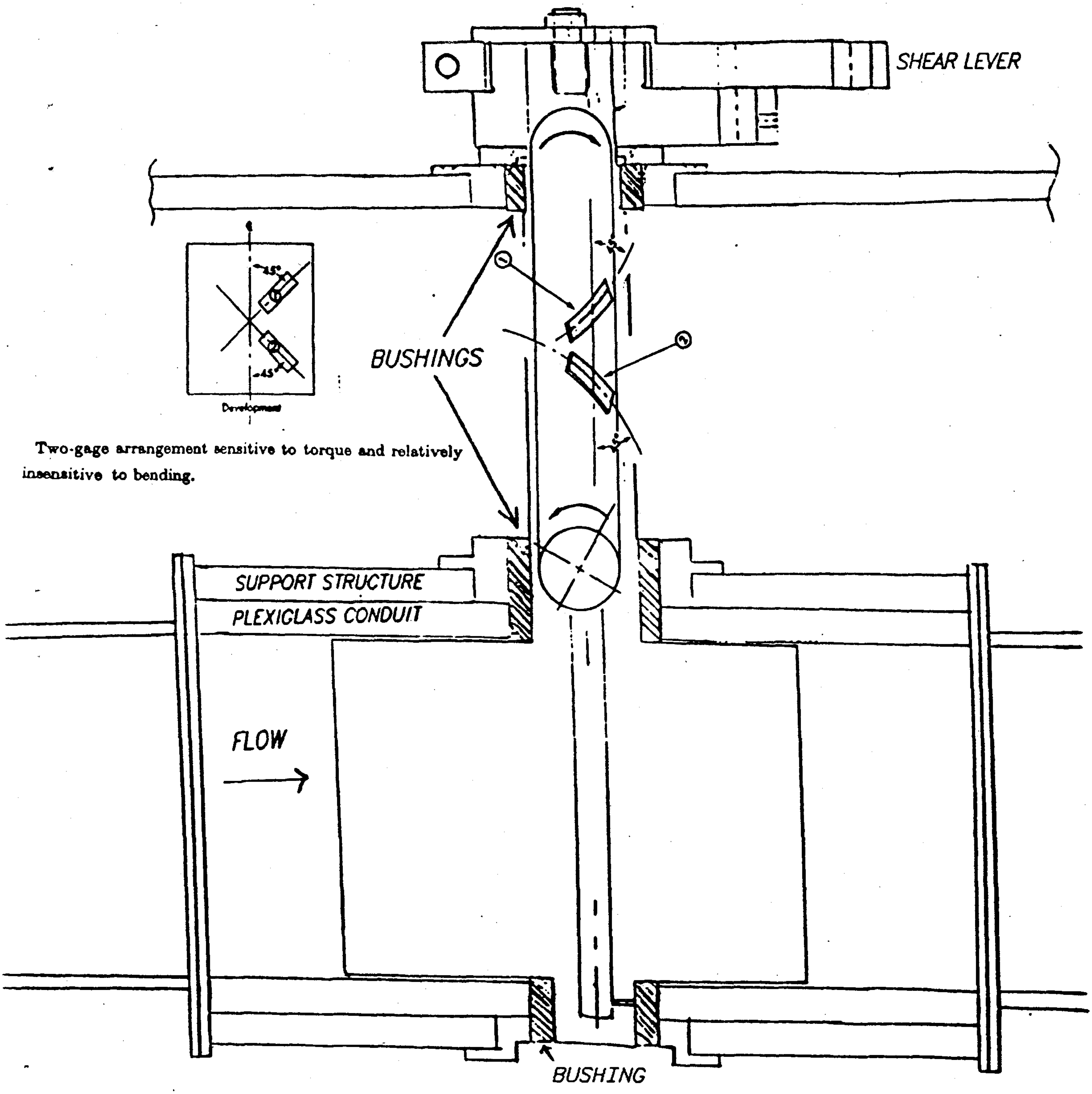
SIDE VIEW



TOP VIEW

FIGURE 1.

WICKET GATE MODEL



Two-gage arrangement sensitive to torque and relatively insensitive to bending.

FIGURE 2.

APPENDIX A

Greaseless Bushing Tests - Powertech Inc.

Powertech Inc. evaluated the following bushings on the basis of wear, coefficients of static and dynamic friction, and temperature rise.

Deva metal
Oiles SP500
Lubron AQ100
Lubron AQ30
Fibreglide 64
Thordon SXL

Materials evaluation and expected performance were also included in Powertech's report.
The following is a brief summary of those tests and results.

Test Conditions

The bushings were subjected to the following test conditions:

1. Constant radial bushing pressure: 3000 psi (20.7 MPa) radial over the projected area of the bushing as stated by one turbine manufacturer.

2. Minor oscillations: ± 2 degrees continuously at a 2 hz frequency except during major swing.

3. Major swing: ± 15 degrees once every 15 minutes.

4. Length of test: 120 hours. This was felt to represent approximately 2 years of normal operation of a typical unit.

5. Tests were run under both wet and dry conditions. Since water conditions vary from damsite to damsite, it was decided that for consistency to use distilled water in all wet tests.

Conclusions

The Thordon SXL bushing manufactured by Thomson-Gordan was recommended by Powertech Inc. for wicket gate service. This bushing had negligible wear and had the second lowest coefficients of friction of the bushings tested. In addition the manufacturer claims these bushings function in an abrasive environment without the need to install seals and can be machined easily to finished sizes using conventional metal working tools. Powertech notes that this style of bushing was originally designed for rudders in large ships and appears to be suited for wicket gate application (another moist environment with cyclic motion).

The Fibreglide bushing performed the best throughout the mechanical tests having the lowest coefficients of friction and negligible wear. However, to maintain performance in contaminated water conditions the supplier recommends bushing seals. There is concern about the additional cost in material and time of installing these bushings because of the seals. This bushing consists of a fabric composite of PTFE (teflon) and glass fibers impregnated with a mineral oil lubricant and then embedded in a phenolic resin matrix. Powertech expresses concern that these oil impregnated bushings may not be suitable for long term use without maintenance. Their tests were not long enough to evaluate the possibility that the lubricant may be leached out of the bushing.

The other bushings did not perform as well as the two stated above. The bushings with lubricant plug inserts (Lubron AQ30,Lubron AQ100, and Oiles) and the metal composite (Deva metal) performed the most poorly in these tests. The Deva metal bushing had the highest coefficients of friction and highest wear rate throughout the tests. The Lubron AQ100 had a severe sticktion problem in this oscillating application where a higher coefficient of static friction becomes more significant. The AQ100 bushing may be more suitable for rotating applications.

Material evaluation

The Thordon SXL bushing showed the most promise throughout Powertech's material evaluation. This bushing is a polyurethane based resin bonded to a bronze backing. Polyurethane falls under the category of elastomeric resins and would be much more resistant to fatigue and brittle failure then epoxies or phenolic resins. This would be more important in oscillating applications like the wicket gate then in rotating applications.

One of the concerns associated with the impregnated lubricants used in some bushings is the limited life of this type of bushing. The life of the bearing would be limited by the finite supply of lubricant in the bearing, the amount that would reach the bearing surface, and the oxidation resistance of the lubricant material.

Recommendations

Powertech recommends that bearings with less than 80% lubricant coverage not be selected. Materials with liquid type additives (oil) should be considered, but additional tests on their ability to leach out oil should be addressed. They also recommend that consideration be given to the provision of manual greasing even for self lubricating bushings since this could extend the service life of the bushing.

APPENDIX B

Selection

Of

Suitable Bearing Material

For

Aswan High Dam Turbine

Wicket Gate Stem Bushings

By

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INTRODUCTION

It is essential that the Aswan turbine wicket gate bushings be guaranteed a reliable, trouble free operation over a twenty to thirty year period of time. This time period is generally accepted in the hydroelectric industry as an acceptable bushing life span. No industry research, that we are aware of, is currently being conducted to determine the life span of various wicket gate stem bushing materials. Since replacement of the wicket gate bushings requires a major maintenance activity, it is essential that the proper bearing material be selected for these bushings.

When selecting a suitable bushing material the following criteria should be evaluated:

* Load Capacity
* Susceptibility to Dirt and Foreign Particles
* Wear Thickness Layer
* Corrosion Resistance
* Coefficient of Friction
* Susceptibility to Solvents and Oils
* Susceptibility to Temperature Variations

For a correct selection of bushing material all of the above factors shall be taken into account to avoid premature failure.

CONCLUSIONS

Our findings indicate that if a life expectancy of 25 years is required for the wicket gate stem bushings at Aswan, no documentation or field experience currently exists that shows any type of plastic-based self-lubricated bushing will provide trouble free operation over this long a service life. None have been installed for 25 years. Due to the problems associated with having an adequate amount of lubricant on the rotating wicket gate stem surface, the metal-based solid type bushing with lubricant plugs can not be recommended either. The only self-lubricated bushing that may possibly have this long a life expectancy is the metal-based tin-bronze bushing with impregnated graphite.

If self-lubricated bushings are not utilized, the only type of bushing proven by experience to have the 25 year life expectancy is the grease lubricated bronze bushings that were originally furnished on the Aswan units. The environmental problems and continual maintenance of grease lubricated bushings and equipment has to be weighed against the possible shorter life span of self-lubricated bushings when selecting the proper wicket gate bushing material for the Aswan turbine units.

TYPES OF BUSHINGS

There are two basic types of wicket gate bushings, "self-lubricated" and "grease lubricated".

Self-Lubricated

The self-lubricating types would include bushings that utilize a thin dry film lubricant, plugs that contain a solid teflon lubricant or a liner which normally incorporates some form of solid teflon or plastic-based lubricant. The dry film lubricant is extremely thin while the teflon or plastic-based lubricant liner is thicker.

These self-lubricated bushings often are broken down into the following two categories:

1. Metal-based: This type of bushing consists of a bronze substrate with a bronze-lubricant innerstructure. Metal-based bushings consist of two types.

    a. Tin-bronze material with graphite lubricant dispersed throughout - An example would be DEVA Metal Strip.

    b. Solid type with lubricant plugs - An example would be Lubron AQ30, DEVA Devaglide, Oiles, or Lubrite.

2. Plastic-based: This type of bushing consists of either a metal or plastic backing material with a teflon or plastic lubricant innerstructure. Plastic-based bushings come in many different varieties.

    a. Teflon/Dacron fabric glued to a metal or molded phenolic backing - An example would be Fiberglide.

b. Teflon-Lead overlay on a bronze innerstructure with a steel backing - An example would be Garlock DU.

c. Teflon Liner - Teflon liner mechanically held in a bronze bushing - An example would be Lubron AQ100.

d. Plastic - Synthetic, polymer alloy bushing, can be glued into a metal backing - An example would be Thordon or Delrin.

Grease Lubricated

The grease lubricated type is a solid bronze bushing that operates with an externally supplied grease lubricant. The thin layer of grease between the bushing and wicket gate stem prevents metal to metal contact between these two components. The grease lubrication system usually consists of a fully automatic, air powered, centralized lubrication system that supplies each wicket gate stem bushing with the proper amount of grease lubricant.

Comparison Of Self-Lubricated And Grease Lubricated Bushings

Self-Lubricated Bushings	Grease Lubricated Bushings
One time initial cost	Continual cost due to purchase of lubricants
Not harmful to the environment	Harmful to the environment due to the release of lubricants into the water supply
Top of headcover and gate operating mechanism is clean which results in a reduced accident risk to maintenance personnel	Lubricant contamination on top of headcover and gate operating mechanism with increased accident risk to maintenance personnel
No maintenance	Lubrication equipment requires maintenance
Long life possible only with proper selection of bushing material	Long life

PROBLEMS ENCOUNTERED WITH SELF-LUBRICATED WICKET GATE BUSHINGS

Various problems have been encountered with self-lubricated wicket gate bushings which have led to premature bushing failure and subsequent maintenance activities.

Some types of plastic-based wicket gate bushings cannot be machined to correct any flaws or damages caused during installation. Metal-based bushings can be honed or deburred to correct any imperfections.

Since some plastic-based bushings are glued into the bearing backing, glue failures have been reported.

Certain types of solvents and oils can affect the bushing surface on some plastic-based type bushing materials.

The susceptibility of the thin teflon coating liner breaking apart on plastic type bushings such as the Lubron AQ100 and subsequent opening of the original design clearances can lead to the destruction of the bushing.

Problems have occurred with the metal-based solid type bushings with lubricant plugs such as Lubron AQ30 or DEVA Devaglide. The lubricant plugs can get loose with time. Also the wearing action on the lubricant plugs, cups them away from the rotating surface which keeps the lubricant from contacting the rotating shaft surface. Also, due to the limited rotational travel of the wicket gate stem, the solid plug lubricant may not be dispersed over the entire stem area. This results in metal to metal contact without the benefit of lubrication, thereby increasing the rate of wear.

Galvanic action and subsequent corrosion of the wicket gate stem mating material has been reported with the use of metal-based tin-bronze bushings impregnated with graphite.

Wicket gate bushings are typically exposed to water, mud, silt and other external influences all of which have a direct effect on the sliding performance and therefore the life of the bushings. Although the Aswan wicket gate bushings have a seal which is used to prevent the entrance of foreign particles, particles could work there way past the seal and enter the bushing gap. When these particles are embedded into the surface of a softer sliding surface such as teflon or plastic fibers, they could in effect function as an abrasive by gradually scratching and scoring the surfaces of the mating shaft. Because of its metallic structure, the metal-based bushings such as DEVA Metal Strip will not permit foreign particles to become embedded in its sliding surface. In addition, the metal-based bushings such as DEVA Metal Strip can be manufactured with "self cleaning grooves" which resemble a crossed hatched groove pattern. This could significantly improve the operating properties of the bushing since any foreign particles that enter the bushing gap would now have an "escape route" so they do not interfere with the sliding surfaces. This could be an especially important benefit when working in water that is highly contaminated or polluted.

The thickness of the sliding layer can influence the life of the bushing. Since deflection of the wicket gate will occur during operation, a sufficient wear surface is necessary so that the sliding layer is not worn away due to edge pressures on the bushing material. For this reason the thinner sliding surfaces of plastic-based bushings are much more susceptible to rapid failure than metal-based bushings.

The plastic-based self-lubricating bushings have a friction coefficient that is lower than the metal-based bushings; however, friction coefficient is just one criteria when selecting a suitable bushing material. The coefficient of friction is influenced by the bearing load, velocity, temperature, finish and hardness of the mating material. Friction is of less practical importance than is the rate of wear.

To assure satisfactory operation and long life of the wicket gate bushing, the mating material should also be examined. The mating material should also possess sufficient hardness, corrosion resistance and a smooth surface finish.

In order to protect against corrosion, the use of a stainless steel mating material is recommended by various bushing manufacturers. Although they do not specify a particular grade of stainless steel mating material they recommend it meet sufficient hardness criteria. A minimum hardness of BHN > 220 is recommended.

The minimum recommended surface finish on the mating material should be at least 16 - 32 micro-inch.

LOADS

Most of the self-lubricated bushings can theoretically tolerate quite high specific pressure. The actual design load should be significantly lower than the specific pressure to assure the long life of the bushing in the event excessive loads are encountered.

A relatively small design load will result in the long service life required for wicket gate bushings. The effect of load and friction on wear as well as load uncertainties, such as the dynamic hydraulic forces encountered during the operation of the turbine, may cause bushings designed for large loads to fail.

The relatively small load carrying capacity of Teflon and plastic materials should result in the design of larger bushings and accompanying higher costs.

In any wicket gate application the effects of shaft deflection and edge loading impacts directly on the performance of any bushing material. Because of the metallic composition of metal-based bushings they are much more resistant to edge loading than plastic-based bushings with teflon liners which tend to deform under relatively low edge pressures. Some bushing manufacturers recommend as a design guide that the effective edge load should not exceed the static compressive strength of the material being used. Because the dynamic edge load pressures have a direct influence on wear by causing a local embedding of the shaft into the bushing surface, the permissible load is inversely proportional to the frequency of movement under load.

EXPERIENCES

Studies by the Allianz Insurance Group in Germany [2] (Allianz insures over 1300 water turbines) show that the primary causes of damage in wicket gate bushings occur as a result of overstressing and/or lack of lubricant.

Allianz has concluded from their investigations on damages in water turbines that metal-based bronze bushings achieve a life time that is 2-1/2 times longer than that of bushings with teflon inserts. They also concluded that metal-based bushings are not suddenly destroyed since a rigid metal-based self-lubricating layer of sufficient thickness is always present which makes a sudden destruction of the bushing in the presence of extreme edge pressure or special operating conditions practically impossible.

The turbine manufacturer, J.M. Voith of Germany, has conducted field tests on the wicket gate stem bushings at the Alzwerke GMBH turbine unit in Burghausen, Germany. Different types of self-lubricated bushings were installed and the test results seem to show that the metal-based tin-bronze graphite impregnated wicket gate bushings manufactured by DEVA were superior. These metal-based bushings have been in service for 18 years at the present time.

The Canadian utilities, Ontario Hydro and B.C. Hydro, have been retrofitting their turbine units with Thordon plastic-based wicket gate stem bushings. They prefer Thordon over a material such as Fiberglide since Thordon is less susceptible to damage during installation and also because it can be honed or machined to correct any imperfections. A thin layer of Thordon can be bonded into the original bronze bushing material which provides a new sliding surface and lower replacement cost. These Thordon bushings have only been in service for 5 to 10 years with no problems encountered to date.

B.C. Hydro has reported the failure of Lubron AQ100 wicket gate stem bushings on the units at their Schrum Powerplant. These Lubron AQ100 bushings were apparently similar to the Aswan bushings with the exception that the Schrum bushings did not have an overlapping hole pattern of teflon in the bronze backing material and did not have a phonographic finish between the teflon liner and bronze backing material. These bushings failed when corrosion occurred on the carbon steel wicket gate stems which caused the bushing teflon liner to flake off and compress into the bushing operating clearance. At this point the wicket gates could not be opened by the servomotors.

B.C. Hydro has also conducted tests in the laboratory on several different types of self-lubricated bushings. Their tests focused on not just wicket gate stem bushings but other types of self-lubricated bushings used in the construction of a turbine. They did conclude that plastic-based bushings such as Thordon and Fiberglide had a substantially lower coefficient of friction than the metal-based DEVA Metal Strip.

The United States Tennessee Valley Authority has decided they will retrofit their wicket gate stem bushings on future turbine overhauls with either Thordon or Deva Metal Strip. They selected these two materials after studying product literature and discussing the subject with other utilities.

The United States Bureau Of Reclamation has three facilities that have self-lubricated wicket gate stem bushings. The station service units at Grand Coulee were retrofitted with a bushing consisting of a teflon liner bonded to a filament wound composite backing in 1983. The units at Heart Mountain Powerplant were retrofitted with Lubron AQ100 bushings in 1991. The Stampede Powerplant units were initially installed with Fiberglide bushings in 1987. The units at these installations are all less than 15 MW and no bushing problems have been reported.

COSTS

The initial cost of a self-lubricated bushing is higher than a conventional grease-lubricated bronze bushing. However, when the total costs incurred by each of the two types of bushings are compared, the self-lubricated bushing is not more expensive. The costs for the grease lubrication equipment and the continuous costs of lubricant and maintenance on the lubricating equipment will exceed the price of self-lubricated bushings.

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