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Plain Journal Machinery Bearings Subjected to Heavy Loads

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Introduction

Plain journal bearings are used for many different applications. The special case of heavily loaded plain journal bearings present unique requirements for design, fabrication, installation and maintenance. Particularly in cases that have heavy loads where the supports deflect under the initial application of load, hence changing the bearing alignment from the unloaded condition. A major advantage of using a spherical plain bearing or spherical roller bearing would be that these types of bearings would be self-correcting for misalignment. However if care is given in the design, fabrication, installation and maintenance, plain journal bearings can be used very successfully for movable bridges. This paper will discuss the use of plain journal bearings for the specific application of vertical lift bridges. For this case the bearings are used to support the counterweight sheaves and shafts, which in turn support the counterweight wire ropes. The bearings must also provide a lubricated sliding surface that fully supports the sheave shaft during rotation.

Information and photographs from two vertical lift bridge projects exemplifying the use of heavily loaded plain journal bearings will be used throughout this paper. A description of the two bridges is given below:

1) The Duluth Aerial lift bridge in Duluth, Minnesota. Each corner of the lift span is counterbalanced using (12) 2" diameter wire ropes, which are supported by a 12 ft (144") diameter sheave. This bridge is a span drive bridge, with two sets of machinery located on the ends of the span. Up-haul and Down-haul wire ropes are used to operate the span. In 1999 a rehabilitation project was undertaken, which included replacement of the counterweight sheaves, bearings, wire ropes and wire rope connections. (see photographs below)

2) The Route 7 vertical lift bridge in Belleville, New Jersey. Each corner of the lift span is counterbalanced using (8) 2 1/8" diameter wire ropes, which are supported by a 14.17 ft (170") diameter sheave. The bridge is a tower drive bridge, with two sets of machinery located in two lift towers. The machinery drives pinions in each corner, which engages a ring gear mounted to each of the sheaves, which are used to operate the span. In 2000 a bridge project had been undertaken to replace the existing bascule bridge and approach spans.

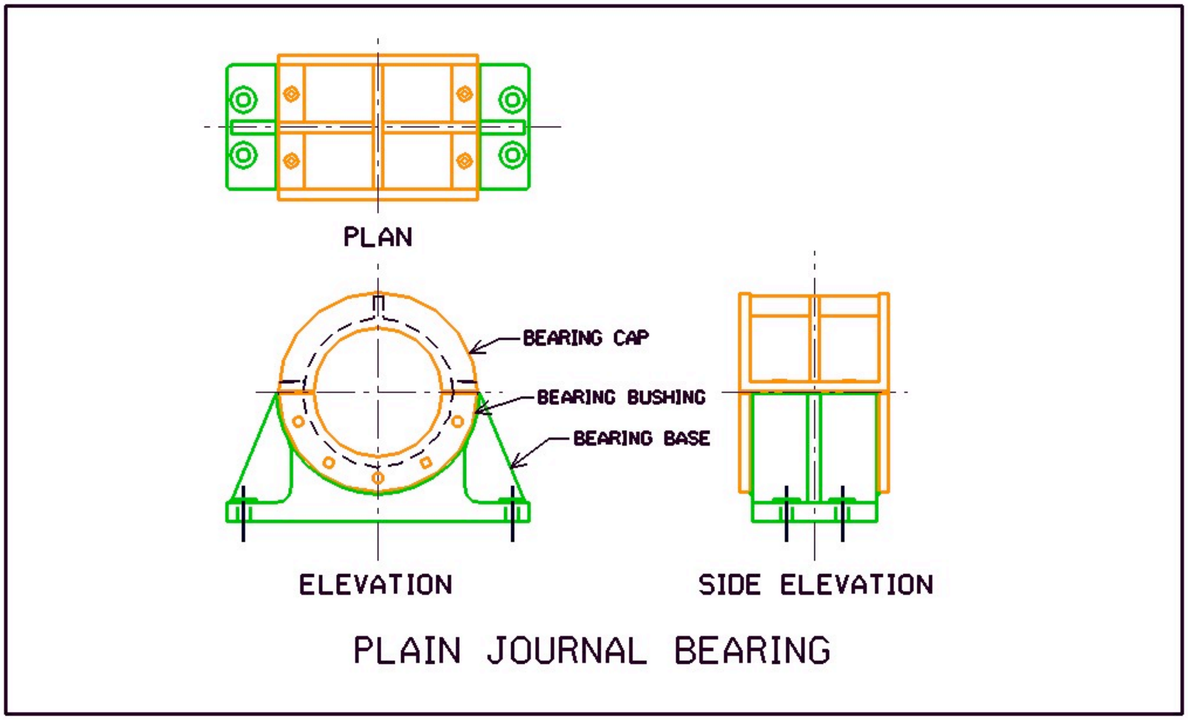
A typical sheave bearing is shown below:

Duluth Lift Bridge- Sheave, Shaft and Bearing

Duluth Lift Bridge- Close-up of bearing assembly

Design

The basic components for a plain journal bearing are shown below:



The first function of the bearing is to support the load. For typical vertical lift bridges the bearing load is a combination of span dead load, counterweight dead load, wire rope weight, sheave/shaft weight and live loads such as wind and ice. Assemblies for which the shaft is forged carbon steel and the bearing sleeve is a tin bronze (alloy 911), the typical allowable bearing pressure is 2.0 ksi for a static condition and 1.5 ksi for a dynamic condition.

Typical shaft journals range from 12" to 30". In most cases the diameter of the shaft journal is controlled by the allowable bending stress in the shaft. The shaft should also be provided with a generous fillet at the shoulder. Usually a radius of approximately 10% of the journal diameter provides a good detail when addressing fatigue.

Both the Duluth Lift Bridge and Route 7 Lift Bridge have 18.1"(460mm) diameter by 21.3" (540mm) long journals with a 1 _" (45mm) fillet radius. The typical allowable loads for a bearing sized for a journal of these proportions would be approximately 445 kip for a dynamic condition and 590 kip for a static condition. The approximate allowable load was calculated considering a deduction in bearing width of 2" for transition radii and a 15% deduction in bearing area due to the grease grooves. These values were used for demonstration only and actual values would need to be proportioned and analyzed for a specific case.

The second function of the bearing is to permit the rotation of the shaft during bridge operation. In order to minimize friction, lubrication is introduced to the sliding surfaces. Grease grooves are now typically located on the bushing journal surface and grease passageways are provided to deliver the lubricant directly to the sliding surface.

Grease grooves should be arranged to provide even distribution over the journal surface of the bearing. The edges of the grooves should be rounded so that the grease is allowed to gradually adhere to the journal surface as opposed to being scraped off.

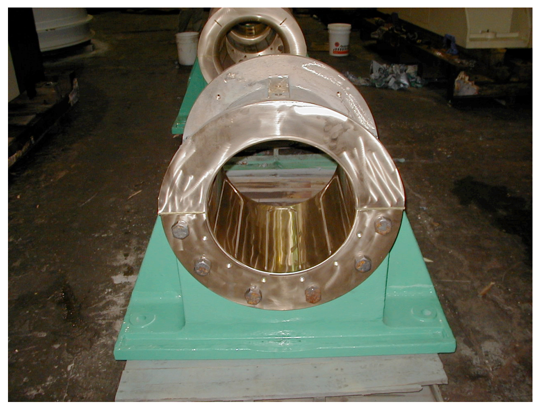
Grease grooves and lube ports should also be provided on the bearing thrust surfaces to reduce friction due to side loads and prevent corrosion from developing.

In some past designs, grease grooves were located directly on the shaft journal surfaces. However, this practice is not common today due to the addition of a stress concentration in a fracture critical member.

Fabrication

The fabrication process for any machinery component is critical. If attention is not applied to details, tolerances and finishes the end result is a component that will most likely not meet its intended function or not work at all.

Route 7 Lift Bridge
Assembly of bushing into the base



Route 7 Lift Bridge
Bearing assembly in the shop

It is also important in the fabrication to hold dimensions and make sure that all machined surfaces are truly parallel or perpendicular to the bearing surfaces. This will not only be helpful for the machining process during setup of the various operations required, but will also aid the field installation by providing accurate reference surfaces.

During the fabrication process it is desired to check critical details, dimensions and finishes. Typically an inspection sheet will follow the bearing through out the fabrication process. After the bearing has been completed, a final inspection should be performed to establish compliance with the shop drawings and Contract requirements. Typical checks to be performed on a final inspection, should include:

- Bearing bore
- Integrity and finish of journal surface
- Journal surface radius
- Geometry of grease grooves
- Housing dimensions

Installation

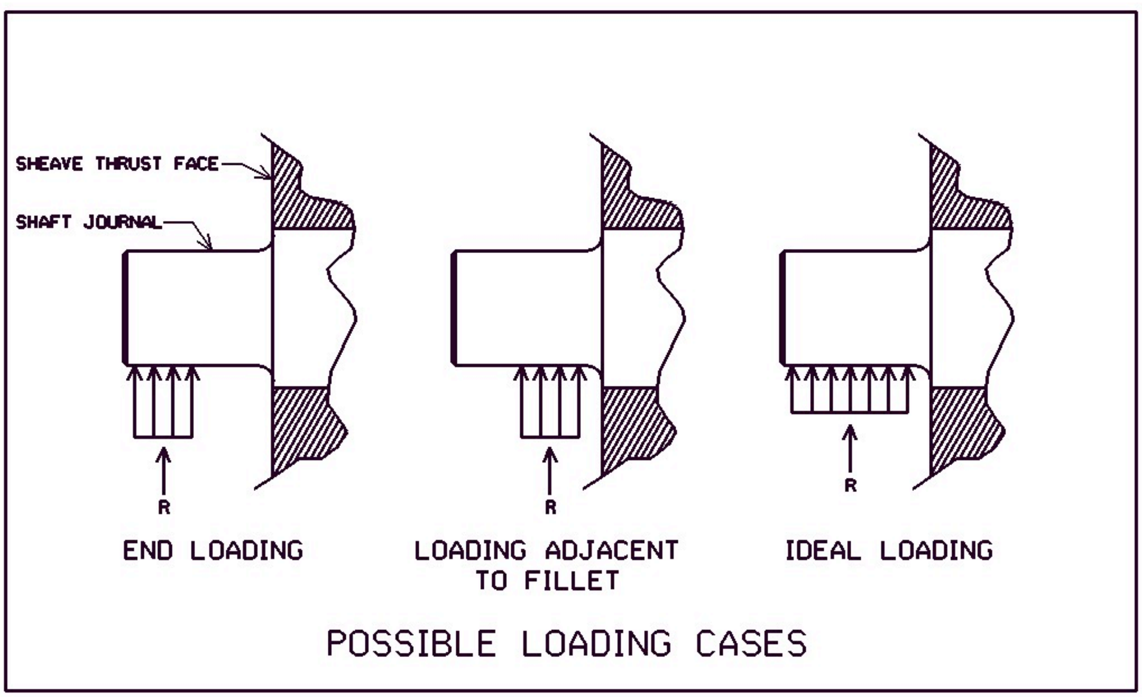
The proper installation of a plain sheave bearing starts with a well thought out plan. The plan for a new bridge will include the coordination with the construction of the lift bridge towers, span, counterweights and wire rope installation. In a rehabilitation project existing conditions must be studied in order to properly install new sheave bearings. The plan should include an initial setting of the bearings, inspection of the loaded condition, and careful observation during the first couple operations of the bridge.

The initial setting of the bearing should be based on the anticipated movement of the structure. This depends on the type of structure used. The two basic types that are fairly common, and are as follows:

- Longitudinal sheave girders supporting each bearing (Route 7 Lift Bridge)
- Transverse sheave girder supporting all bearings of one tower (Duluth Aerial Lift Bridge)

In the first case of the longitudinal sheave girders, they are typical tied into a front and back truss or girder which distributes the loads to the tower columns or truss. For the second case, the transverse sheave girder typically distributes the load directly to the tower columns or truss. It is important to keep in mind the type of structure to understand more accurately how it will behave when the load is applied to the bearings.

Two conditions in which to avoid when setting the loaded bearing alignment, are concentrated end loading and concentrated loading adjacent to the shaft fillet. These conditions are caused when the bearing is tilted with respect to the shaft axis. End loading causes an increase in bending stress due to the increase in the distance from the centerline of sheave to the resultant bearing reaction. This condition also causes elevated bearing stress due to the loss in effective bearing area. Loading concentrated adjacent to the fillet actually causes a decrease in the bending stress because the distance from centerline of sheave and bearing reaction decreases. However this condition also causes an elevated bearing stress due to the loss in effective bearing area. The ideal condition is even contact across the width of the bearing. The possible loading cases described are illustrated below.

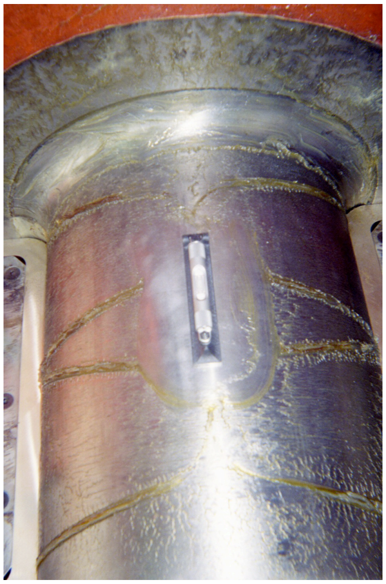


After the load has been applied to the bearings it is important to perform an initial inspection before the actual operation of the bridge to confirm proper alignment of the bearing has been achieved under load.

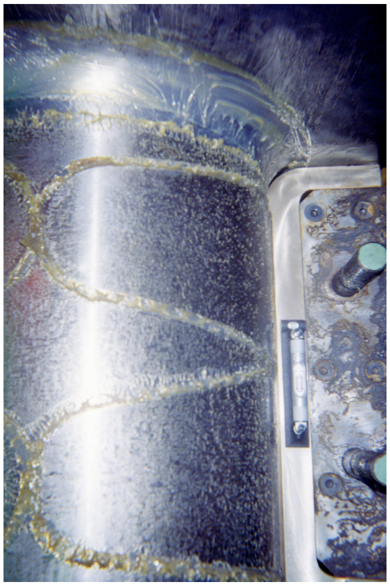
The initial bearing alignment checks under load can typically be performed using an accurate optical survey station or machinist level. In the case of the Duluth lift bridge an optical survey station was used. The corners of the bearing at the split and the shaft elevation across the journal top were taken and recorded. The relative differences in shaft and bearing slopes could than be calculated. A determination could then made to see if the bridge was suitable for operation and final tests performed. An alternate method, as used on the Route 7 Lift bridge, would be to use machinist levels. With this method the shaft and bearing slopes are taken with machinist levels. Again a determination would be made to see if the bridge is ready for further testing under operation.

In general, a difference of slopes of less than 0.005" per foot for the initial check would be consider acceptable. It should be noted that the slope of the bearing at the split used to determine the slope of the bearing, may not be exactly parallel to the journal surface. For the surfaces to be truly parallel would depend on the accuracy of the machining of bearing components and the quality of the assembly of parts. Therefore acceptance of the initial alignment was only for permitting further testing, in which a condition might arise where adjustment of the bearing would still be necessary.

An example of using a machinist level to check initial bearing alignment is shown below:



Route 7 Lift Bridge
Journal slope check with level



Route 7 Lift Bridge
Bearing slope check with level

Another initial check under the loaded condition that needs to be performed is to measure the clearance between the sheave thrust faces and the bearings. It is common for the loaded clearance measurement at the thrust face to change with respect to the un-loaded clearance measurement. This condition is caused by the structural members deflecting as the load is transferred from the temporary supports to the wire ropes, hence journal bearings. Typically the clearance decreases when the load is initially applied. It is very difficult to calculate an accurate amount the clearance will change, therefore the clearance at the thrust face is usually set by multiple loading, unloading and bearing adjustment cycles. However, accurate measurements between these cycles will serve to limit how many cycles would be necessary to achieve the desired results.
Since machining tolerances vary, the clearance measured at the thrust faces needs to be taken and analyzed with care.

When the bridge is ready for operation it is important that the bearings are checked during the first runs of the bridge to make sure there is full contact of the shaft journal with the bearing during shaft rotation. This is typically accomplished through observations of the grease pattern. This is also a good way to confirm the distribution of grease to the journal surface.

A grease pattern check is usually done by removing the bearing cap and operating the bridge at reduced speed if possible. Before this is done a determination has to be made as to whether or not the cap can be removed during operation. This would depend on the details for securing the lower bushing. Typically cap screws secure the flange to the base. With a conservative design the cap screws are sized to resist the rotation of the lower bushing with respect to the base. Caution must be used for inspecting existing bearings, since it is possible in some cases for a designer to consider the capacity of the cap to aid the cap screws.

When the cap is removed care must be given so that no contaminates enter the journal surface at rest or during operation. After the cap is removed and the bridge is operated a very thin grease film can be observed during operation. During this type of inspection it is also important to observe that the grease film is consistent across the width of the journal. This would confirm even pressure across the bearing width. If the film is not consistent across the width of the bearing, a determination must be made to if the degree of uneven contact is in an acceptable range or if the bearing requires readjustment.

An example of checking the grease pattern during operation is depicted below:

Duluth Lift Bridge
Shaft journal check during operation. Actual loaded portion of the shaft is below the accumulation of grease on the shaft end, which is only the result of the cap removal.

Maintenance

The proper maintenance should include a program of periodic lubrication and inspection.

To accomplish this, lubricants should be selected for the specific application. A lubricant with Extreme Pressure (EP) additives is imperative. Application of grease should be scheduled based on time and frequency of bridge operations. A typical frequency would be every 3 months or every 50 openings. However this would have to be studied for the specific case since number of shaft rotations per lift and shaft RPM will vary from bridge to bridge. The schedule should be modified as necessary if field observations indicate a condition of lack of lubricant or excessive lubricant.

It is highly recommended that a lubrication chart be developed for a movable bridge. The lubrication chart commonly contains the information to maintain the lubrication of all components, including the sheave bearings in the case of a vertical lift bridge. The chart should include the types of lubricant, method of application, frequency of application and location of all lubrication points. It is common to use a key on the chart to efficiently list all the information required. Lubrication charts are typically printed on “D” size paper and are mounted in a protective frame in areas close to the machinery as practical. This will provide a tremendous asset to the maintenance crews when servicing the machinery.

It is important that the equipment used to apply lubricant is clean and in proper working order. The grease used should be fresh (within expiration date), and clean of debris or contaminates. If either the grease or equipment contain debris or containments they could be forced into the bearing, which may cause damage to the bearing, journal or raise the operating frictional force.

Typically journal shaft fillets are inspected since they have historically developed into fatigue failure concerns. When inspections are scheduled for the shaft fillets the inspection of the journals should also be checked to avoid excessive disassembly of the caps.

Conclusions

The design and fabrication of plain journal bearings for the specific application of vertical lift bridges, can be successfully accomplished by using available standards and the experience gained on similar bearings. The Installation is critical. Bearings that are improperly installed, will in most cases perform at some level of reliability. However, the condition of a bearing that is incorrectly installed will most likely deteriorate at an accelerated pace. If the bearing is installed with the condition of end loading, an increase in the bending stress of the shaft can cause a shaft that was designed with a theoretical infinite life to have a finite life. The loss of bearing area will also introduce higher bearing stress, increase operating temperature at the bearing surface and could result in loss of effective lubrication. It is extremely important to get the installation correct the first time. This will save the great expense of having to unload these components in order to correct the alignment, repair or replace the bearings.

The maintenance of plain journal bearings is fairly straight forward. It must be implemented from the start and the schedule updated based on operational conditions. Inspections will also help to pinpoint problems before they become critical.

As a final summary, listed below are the critical stages in the use of plain journal bearings, subjected to heavy loads:

Design – handle the load and provide lubricated sliding surface

Fabrication – check details, dimensions and finishes

Installation – have thought out plan and implement it, verify loaded alignment

Maintenance – use proper grease at proper intervals and inspect as necessary

Acknowledgements:

Duluth Aerial Lift Bridge (1999-2000 Mechanical & Electrical Rehabilitation)

Owner: The City of Duluth

Contractor: The Lunda Construction Company

Machinery Fabricator: Mobile Pulley and Machine Works

Designer: Hardesty & Hanover, LLP

Machinery Inspection: LHB Engineers and Architects and Hardesty & Hanover, LLP

Route 7 Lift Bridge (2000-Present Construction)

Owner: New Jersey Department of Transportation

Contractor: M. J. Paquet, Inc.

Sub-Consultant for the Machinery Installation: Stafford Bandlow Engineering, Inc.

Machinery Fabricator: Steward Machine Company

Machinery Designer: Hardesty & Hanover, LLP

Machinery Inspection: BRH Consulting, Inc.