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Miller Park – Pivot Bearing Replacement

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Introduction

Miller Park, home to the Milwaukee Brewers professional baseball team, is located just outside of downtown Milwaukee, WI. Miller Park planners decided in the mid-90's that due to the regions climate the original open-aired County Stadium would be replaced with a state of the art retractable roof stadium. The idea was simple, provide the public with a signature stadium that offers a comfortable atmosphere from April through October for viewing baseball games, rain or shine.

The design for the retractable roof is comprised of two fixed panels (panels 4L and 4R) and five movable panels (panels 3L, 2L, 1L, 2R and 3R). The two fixed panels are trapezoidal-shaped (in plan view) and arch over the stands along the third and first baselines. The five movable panels are all triangular-shaped (in plan view) and arch over the field.

Each movable panel is supported at its pivot end (behind home plate) by a spherical thrust bearing and at the running end (beyond outfield), or periphery, at a radius some 600-feet, by powered bogies running on a heavy steel rail. Each movable panel weighs between 3,500,000 lbs to 5,000,000 lbs (or 3,500 kips to 5,000 kips) and approximately 40-percent of that weight is supported by the pivot bearings. The pivot bearings of adjacent roof panels are at different elevations, while the bogies of adjacent roof panels are at different radii. To open the roof, the center panel (panel 1L) and two adjacent left panels (panels 2L and 3L) travel toward the stands along the third baseline while the two adjacent right panels (panels 2R and 3R) travel toward the stands along the first baseline. Each movable panel is rotated about its pivot bearing to form stacks over both sidelines of the baseball field below.

Photo 1: Roof panels shown in the closed position.

Photo 2: Roof panels shown in the open position.

During Miller Park's inaugural season in 2001, the retractable roof experienced operational problems, most notably at the movable panels pivot bearings. Noises audible above the background ball game began emanating from the pivot bearings while the panels were in motion.

Hardesty & Hanover, LLP (H&H) was employed by the Southeast Wisconsin Professional Baseball Park District (SEWPBPD), in April 2002, to assist LZA Technology (LZA), a Division of Thornton-Tomasetti Group, in the investigation of the mechanical and electrical aspects of the retractable roof problems. With respect to the pivot bearings, it was determined that they were not completely rotating on their intended "wear" surfaces; that the noises emanating from the bearings were a result of a "stick-slip" condition; and that their performance was further affected by apparent deficiencies in design details. With respect to the panels, it was determined that the driving force at the bogie end was sufficient to separate the roof from the pivot bearing assembly should sufficient "lock-up" occur.

A monitoring program was implemented for the 2002 baseball season to determine if there was any further degradation of the bearings and to provide a warning system to stop the motion of the roof in the event of a bearing failure. At the end of the 2002 baseball season, the volume of the noise emanating from the bearings continued to increase. In addition, observers standing on the pivot support structure felt perceptible vibrations. As a result, the owner chose to replace each of the five pivot bearings by the start of the 2003 baseball season and directed H&H and LZA to engineer the project.

Background

The original pivot bearing assemblies were made up of (4) four major components, the top plate (shaft), spherical plain thrust bearing (SPTB), bottom plate (housing) and base plate. Given the design details, it was our understanding that fabrication and assembly occurred as follows:

- The top plate (shaft) was welded to the underside of the roof panel's pivot end (tub)
- The top plate (shaft) was machined after welding and stress relieving
- A lube retainer and uplift guarder post were welded to the bottom plate (housing)
- The bottom plate was machined after welding and stress relieving
- The base plate was machined and prepped for field welding

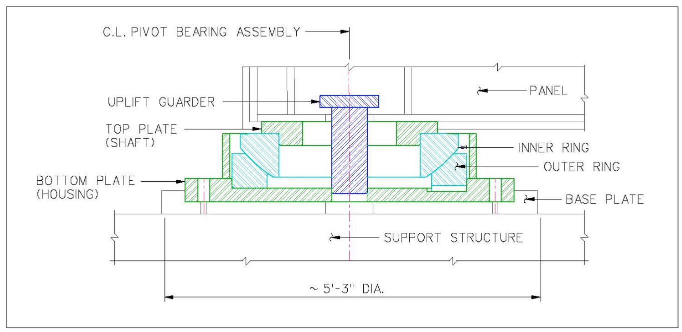

Figure 1: Original pivot bearing assembly with spherical plain thrust bearing - steel on steel.

In addition, it was our understanding that the installation and alignment was performed as follows:

- The top plate (shaft) was fitted with the SPTB's inner ring
- The bottom plate, lube retainer and uplift guarder post were fitted with the SPTB's outer ring
- The inner ring, top plate (shaft) and tub were lowered to allow the uplift guarder post to engage the interior of the tub
- The uplift guarder post was fitted with an uplift guarder cap
- The assembly was prepared to be lifted into place
- The base plate was installed and aligned in the field
- The base plate was welded to the pivot support structure
- The bearing assembly was lifted, allowing the uplift guarder to bear the weight of the bottom plate and outer ring
- The bearing assembly was placed in close proximity to its final location and the bottom plate and outer ring were manipulated to engage with the base plate
- The bearing assembly was lowered, allowing the inner ring to engage the outer ring and self align

This detailed understanding of the original design and basic understanding of the intended installation techniques was useful in developing the suggested bearing removal procedure and in assuring the replacement design complimented the existing fixed and retractable roof structures while still meeting the applications needs.

Design Considerations

Provisions for bearing replacement were not built into the original stadium design, and access to the pivot bearings was achieved by a series of narrow catwalks on the inside of the pivot frame that were not suitable for supporting heavy construction loads. The original bearing housings were welded in place, requiring a series of machining operations in order to remove the bearings without adversely affecting the existing mounting surfaces. Also, any jacking steel added during the project was to remain after the bearing replacement project was complete to provide the ability for future repairs or replacements.

Since the design phase of the project began in early September 2002, construction would need to be performed during the cold Milwaukee winter. While one half of the design team was busy developing a scheme to lift each roof panel at the pivot bearings, the other half was busy qualifying a bearing that could be manufactured, delivered, housed, installed and tested before March 2003.

Designers presented two bearing replacement options to the SEWPBPD. The first option was a spherical plain thrust bearing, similar in style to the original bearing but utilizing a sacrificial self-lubricating bronze wearing material to promote rotation. The second option was a spherical roller thrust bearing, different in style from the original bearing and utilizing special rollers to promote rotation. Both options are widely accepted and used successfully in similar heavy movable structure applications, such as swing bridges.

Ultimately, H&H recommended that the original bearings be replaced with spherical roller thrust bearings for the following reasons:

- Standard design, commercial cataloged item
- Accommodates high thrust and moderate radial loads
- Accommodates slight angular misalignment
- Low starting coefficient of friction
- Inspection, both visual and aural, is possible without jacking

The design schedule, as well as all phases of the project, was fast paced, requiring full commitment and often weekend involvement to properly coordinate all aspects of design, fabrication and construction. Given the project time constraints, it was often required that long lead items be purchased in advance of completing the design of their mating components. Although this method can successfully limit the time required to complete fabrication of a design, it has its risks, requiring an increased level of coordination and designer foresight.

During design, an extensive coordination effort was spent with the selected bearing manufacturers to ensure that adequate stiffness of the supporting elements of the bearing was achieved. Because the details of the existing structure that dictated load paths, such as bearing stiffener locations could not be changed, development of details to ensure even distribution of load to the bearing rollers was not straightforward. Ultimately, housing details were developed that met bearing manufacturer requirements for load distribution and worked within the constraints of the existing structure.

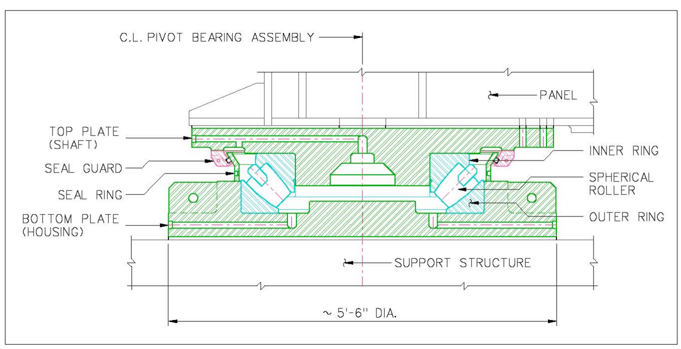

Figure 2: Replacement pivot bearing assembly with spherical roller thrust bearing.

With a considerable coordination effort between the design teams and proposed manufacturers and fabricators, the design was completed in November of 2003.

Construction

In order to successfully remove the original assemblies, LZA designed a plan where the roof panels were secured in their "jacking" position, working platforms were fabricated and installed at each pivot location and jacking brackets were fabricated and welded to the fixed and retractable roof structures. The jacking brackets enabled hydraulic jacks to lift the retractable roof panels, transferring associated roof loads from the original assemblies to the brackets. The load at the pivots ranged from 1,400,000 lbs to 2,000,000 lbs (or 1,400 kips to 2,000 kips). With the brackets properly positioned, secured, tested and loaded, the original assemblies were removed by machining through the welds used to secure the top and bottom plates to the roof panels and support structure, respectively. The assemblies were removed carefully so as to minimize the surface damage to the existing structure, which would be the mounting surface for the replacement assemblies. The original assemblies were also immediately crated and preserved for forensic testing at a later date.

Photo 3: Panel 1L, pivot end shown in the raised position prior to removal of original bearings.

With the original assemblies removed and the roof panels supported by jacks, the top surfaces of the fixed structure were measured for levelness and flatness and bottom surfaces of the roof panels were measured for flatness. The goal was to install the replacement assemblies so that the majority of the bearings misalignment capacity would be utilized during panel movements rather than during installation.

Photo 4: Panel 1, pivot end shown in the raised position after removal of original bearing.

Having measured the top surfaces of the fixed structure, a "best fit" plane was determined in order to field machine the existing mounting surface flat to within 0.010-inch by removing a minimal amount of material. The machining effort allowed for a tapered lower shim plate of equal flatness to mate with the field machined surface and provide a level mounting surface for the replacement assembly. Based on the measurements of the bottom surface of the roof panels, a "best fit" plane was determined in order to field machine an area larger than the existing mounting surface flat to within 0.010-inch by removing a minimal amount of material. Because the

Photo 5: Panel 1L, bottom surface of roof panel after field machining.

replacement assemblies upper housing was significantly larger than the original, this machining effort was necessary to allow for proper mating with the roof panel.

Starting from the bottom, a tapered lower shim plate was positioned on top of the reconditioned fixed structure's mounting surface and checked for levelness. Once level, the replacement assembly was positioned on top of the lower shim plate and the two were aligned to match the pivot position of the original assemblies. This was achieved by utilizing benchmarks that had been established prior to the removal of the original assemblies. With the lower shim plate and replacement assembly aligned with the fixed structure, the lower shim plate position was secured and the replacement assembly was temporarily removed. The pre-drilled lower shim plate was then used as a template to drill and tap mounting holes into the fixed structure for permanent mounting fasteners. With the drilling and tapping complete, and surfaces cleaned free of machining debris, the replacement assembly was positioned back into alignment for the second stage of installation. Mindful of the goal to maximize the bearings misalignment capacity after installation, it was decided that a similar tapered shim plate would be necessary on top of the replacement assembly.

The next step was to determine the geometry of the upper shim plate by allowing the roof panel to fully bear on the replacement assembly and define its natural un-jacked resting position. To do this, the roof panel was gradually lowered allowing the upper portion of the replacement bearing assembly to align itself under no load and compliment the slope of the roof panel. With the roof panel lowered to where no gaps existed between it and the replacement bearing assembly, load was transferred from the jacking system to the replacement assembly. At this point the lower housing plate was again verified as level; the position of the replacement assembly was again verified as matching the original; and the upper housing plate was measured relative to its lower housing plate. The vertical distance between upper and lower housing plates was measured at the same radius along its circumference. The minimum and maximum measurements and their locations relative to the upper housing plate (roof panel) were determined in order to define the upper shim plate. The advantage of using the roof panel to define the shim plate taper was that it eliminated any guesswork associated with the actual final position of each panel on its replacement bearings.

Photo 6: Panel 3L, installation of upper shim plate.

With the upper shim plate fabricated and delivered to the site, the roof panel was raised, transferring load back onto the jacks. The shim plate was installed and the roof panel was lowered just shy of the shim plate. At this point the upper housing plate was verified as being properly centered with the roof panel. The roof panel was then lowered, allowing the load to transfer from the jacking system to the replacement assembly. The vertical distance between the upper and lower housing plates were measured a final time at the same radius along its circumference to verify the bearings position. With the bearing position accepted, the upper shim plate position was secured and the panel was raised, allowing the replacement assembly to be removed for the last time. The pre-drilled upper shim plate was used as a template to drill and tap mounting holes in the roof panel for permanent fasteners. With the drilling and tapping complete, and surfaces cleaned free of machining debris, the replacement assembly was repositioned back into alignment for final securing and testing.

In the end, all mounting surfaces were field machined to within 0.010-inch across their entire length and all replacement bearings were installed to within 0.100-degree of angular misalignment. Overall, a total of (3) three raising and lowering operations were performed for each of the (5) five replacement bearings. Although this may seem tedious, designers felt it was necessary to ensure proper fit-up with the existing structure and long-term performance of the replacement bearing assemblies.

Unlike the original assemblies, which were welded to the fixed and retractable roof structures, the replacement assemblies were secured by means of high strength fasteners. This feature minimizes the fieldwork that would be required for any future inspection, rehabilitation or replacement work of the bearings. With remarkable coordination efforts between the owner, the engineers, the contractors and suppliers, workers were able to successfully design, fabricate, install, test and make operational five new pivot bearing assemblies in just 6-months, meeting the projects goal of having the retractable roof panels operational before the first exhibition game on March 28, 2003.

Photo 7: Panel 1L, installation of replacement bearing completed.

Acknowledgements:

Miller Park – Pivot Bearing Replacement (Completed March 2003)

Facility Owner and Operator:
Southeast Wisconsin Professional Baseball Park District (SEWPBPD), Milwaukee, WI

Construction Manager:
Clark Construction, Bethesda, MD
Hunt Building Corporation, El Paso, TX

Steel Contractor:
National Riggers and Erectors (AISC member), Plymouth, MI

Machining Subcontractor:
In-Place Machining, Milwaukee, WI

Machinery Fabricator:
Steward Machine Co., Birmingham, AL

Bearing Manufacturer:
The Torrington Co., Tiger River, SC

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