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MILLER PARK – CLOSING THE CHAPTER ON RETRACTABLE ROOF PROBLEMS

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Introduction

Miller Park, home of Major League Baseball's Milwaukee Brewers, has required extensive rehabilitation efforts to the machinery components that allow the facilities 10 million pounds of movable roof panels to open and close on demand.

Since Miller Park's inaugural season in 2001, the facilities roof mechanization equipment has required major construction efforts in the form of replacement or rehabilitation projects roughly every other post baseball season in an effort to keep the movable roof operating up to the Planners and Users expectations.

Since post baseball season 2002, the movable roof (5-total panels) has had all five pivot bearings replaced, major components of the original drive mechanisms (bogies) replaced, the bogies rail support system rehabilitated (2100 linear feet) and all ten bogies replaced. Should the Planners have avoided introducing a major movable element to their state of the art facility? The answer is no. And those who are still involved today, after a decade of planning, four years of construction and the last seven years of necessary improvements will tell you that the movable roof is the defining element of this multi-functional facility.

This paper will focus on many of the challenges faced between the winter of 2005 and spring of 2007 in order to properly fabricate, assemble, test, and install ten (10) new replacement bogies as well as re-commission the retractable roof.

Background

Miller Park's 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 base and first base lines. 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 roller thrust bearing and at the running end (beyond outfield), or periphery, at a radius some 600-feet, by two powered bogies running on curved steel rail. Each movable panel weighs between 3,500,000 lbs and 5,000,000 lbs (or 3,500 kips and 5,000 kips) with approximately 40-percent of that weight supported by its pivot bearing and the remaining 60-percent supported by its powered bogies. The pivots of adjacent roof panels are at different elevations, while the bogies of adjacent roof panels are at the same elevation but different radii. To open the roof, the center panel (1L) and two adjacent left panels (panels 2L and 3L) travel toward the stands along the third base line while the two adjacent right panels (panels 2R and 3R) travel toward the stands along the first base line. Each movable panel is rotated about its pivot to form stacks over both

Photo 1: Roof panels shown in the closed position.

Photo 2: Roof panels shown in the open position.

sidelines of the baseball field below.

During Miller Park's inaugural season in 2001, the retractable roof experienced operational problems, most notably at the movable panels pivot bearings. The pivot bearings were found to be inadequate for proper long-term service and were replaced by the Southeast Wisconsin Professional Baseball Park District (SEWPBPD) prior to the 2003 baseball season.

During Miller Park's third season in 2003, the retractable roof continued to experience operational problems at the movable panels running end. During panel movement it was reported that the rails support system was showing signs of premature failure, that major components of the bogies were making loud repetitive noises and that the guide system was seeing movement and loads beyond those originally anticipated.

Due to each of the systems design and installation deficiencies, the overall question of reliability and increasing maintenance costs, the SEWPBPD decided to rehabilitate the rail support system prior to the 2005 baseball season and replace the bogies as well as rehabilitate the guide system prior to the 2007 baseball season. Some of the major benefits associated with having moved forward with these rehabilitation and replacement schemes are as follows:

- improved load carrying capacity of rail support system
- improved load and interaction between rail and bogie wheels
- improved load distribution with 4-wheel bogie arrangement
- improved sizing or capacity of bogie components
- improved load and interaction between guide rails and rollers
- increased reliability and decreased maintenance costs

Replacement Bogies Description

The replacement bogies are made up of four (4) major subassemblies; the expansion assembly, idler truck assembly, driven truck assemblies, and drive machinery assembly.

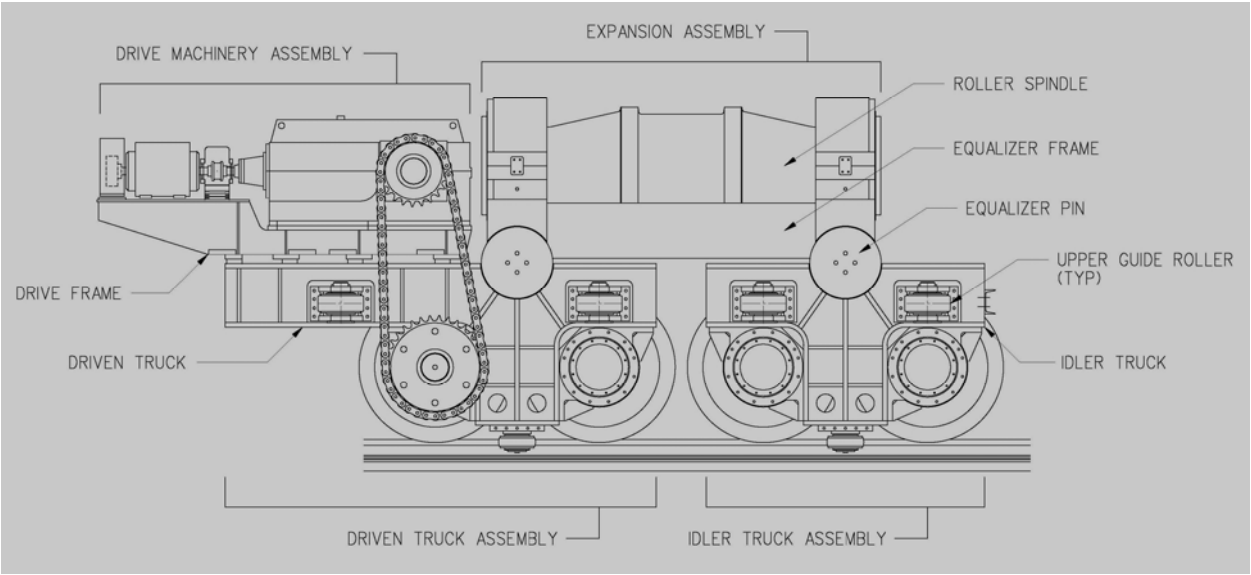

Figure 1: Replacement Bogie Outline - Side Elevation

The expansion assembly is essentially a simply supported roller spindle. On either end of the roller spindle are bearings. The bearings are supported within steel housings, which are connected at their bases by an equalizer beam. The housing bases and beam form a common frame often referred to as an equalizer frame. The underside of the housing bases have half bores, which allow the equalizer frame to nest atop equalizer pins. The expansion assembly helps to support the movable panel, distribute the panel loads equally to two truck assemblies below, and allow the panel to move relative to the bogie or fixed structure in the longitudinal (radial) direction.

The idler and driven truck assemblies are essentially two-wheeled in-line frames. Each of the truck assemblies are made up of welded steel frames, two large diameter wheel assemblies, four upper guide rollers and two lower guide rollers. The top sides of the steel frames incorporate a pin carriage detail. The carriage has half bores, which allow an equalizer pin to nest within the carriage. With the equalizer pin installed within the truck frame carriage, each truck frame supports half the load taken by the expansion assembly overhead. The truck frames distribute loads equally to their wheels below, which are capable of rolling along a curved steel rail.

The main difference between the two truck types is the driven frame extends outward, approximately four additional feet, to provide a mounting support for the drive machinery.

The drive machinery, comprised of an electric motor with brake, reducer, chains, and sprockets, is mounted to an independent common frame. The machinery and frame assembly are located on the driven frame extension, which serves to support the machinery and allow the chains to connect between sprockets. The drive machinery is capable of moving the bogie assemblies at approximately 50 feet per minute in order to open or close the roof panels.

Replacement Bogies Schedule

The replacement bogies were designed during 2004. Toward the end of the year a bid package was prepared and submitted to the SEWPBPD for distribution. The bid process resulted in the selection of Steward Machine Company, Birmingham, AL, to perform fabrication and delivery and Hunt Construction Group, Indianapolis, IN, to perform installation.

As part of the initial agreement, all ten (10) replacement bogies were to be delivered to Miller Park starting in November 2005 for installation prior to the 2006 baseball season. The schedule was later revised to better accommodate winter weather conditions, i.e. to make sure the work was performed prior to winter, and the necessity to have an operable roof by opening day. The project completion date was moved to January 2007.

Replacement Bogies Fabrication

The bogie fabrication effort began in late 2004 with the development of shop drawings and ordering of materials. Of particular importance were long lead items such as large forgings, large commercial bearings, reducers, and special wheels.

The first two of four major sub-assemblies to get started were the truck assemblies. With structural steel plate readily available, the following sequence was utilized to fabricate each truck per its approved drawing:

- order structural steel plate, cut plate to size and bend if necessary
- fit up by tack welding plates to make truck frame
- dimensionally check and weld plates
- test welds and if acceptable send frame out for stress relieve
- machine reference points and specific areas of frame for future assembly
- mask machined areas, blast exposed steel, and paint
- assemble with wheel and guide assemblies

Although the sequence appears straight forward, the work had to be performed twenty (20) times on two different size frames, half of which being idler frames and the other half driven frames.

Photo 3: Idler Truck Frame shown after machining with Wheel Bearing Housings.

Photo 4: Idler Truck Frames shown on work horses during painting.

Similar to the original bogies, the replacement bogies were designed to run along a curved steel rail. To accomplish this, each of the major components on the assembled bogie had to be oriented to compliment the running rail radius. With respect to the trucks, each of the vertical surfaces used to support the vertical legs of the wheel assembly bearings had to be machined at a complimenting angle. The purpose of which was to cant the wheels to compliment the intended direction of roll.

The third of the four major sub-assemblies to get started were the expansion assemblies. With the bearing housings cap and base forgings complete, i.e. forged and heat treated, they could be flame cut to rough shape and delivered to the fabricator.

The bearing housings were then pre-machined to define the cap and base split line and rough machined to remove excess material and prep for welding. With the joining equalizer beam plates cut, the following sequence was utilized to fabricate each equalizer frame per its approved drawing:

- fit up by tack welding plates to make equalizer beam
- fit up by tack welding beam to bases to make equalizer frame
- dimensionally check and weld plates/bases
- test welds and if acceptable send frame out for stress relieve
- machine reference points and specific areas of frame for future assembly
- mask machined areas, blast exposed steel, and paint
- assemble with roller spindle and bearings

Again, although the sequence appears straight forward, the work had to be performed ten (10) times on two different size frames. As noted before, each of the major components on the assembled bogie had to be oriented to compliment the running radius. In addition, the roller spindle had to be oriented to compliment the overhead structure. So for this particular assembly, the housing bores used to support the roller spindle bearings as well as the equalizer pin half bores, located along the underside of the bearing housings had to be machined to different angles.

Photo 5: Equalizer Frame shown with Exp. Brg. Housing being reverse counter-bored.

Photo 6: Equalizer Frame and Roller Spindle shown during shop assembly.

Once the majority of wheel assembly components were received, i.e. forged and rough machined shaft, finished wheel with rough bore, commercial bearings, custom housing materials, etc., the components were finish machined per its approved drawing and prepared for assembly. The basic sequence of assembly was as follows:

- cool shaft and heat wheel to achieve shrink fit
- heat spacer to achieve shrink fit
- install inner ring retainers with seals
- heat bearings to achieve specified fit and install locknut
- install housing over bearings outer race
- install outer ring retainer with seals
- when applicable, install driven sprocket with locking device

The last of the four major sub-assemblies to be fabricated were the drive machinery assemblies. For the most part these assemblies were straight forward in that all of the machinery components were to be mounted square with the drive frame and the drive frame itself was to be made up of welded plate of reasonable thickness and weld type.

Similar to the other frames, the steel plates used to make the drive frames were fit up by tack welding, dimensionally checked and welded. The welds were then tested and once accepted the frames were sent out for stress relieving. The frames were then milled to provide flat and level mounting surfaces, masked, blasted, and painted.

The final step in completing the drive machinery assemblies was to install, align, and secure the drive machinery components to the frame. Most of the drilling and reaming was performed by computer numerical control in order to properly locate and independently drill said components.

Replacement Bogies Shop Assembly

Shop assembly took place after the expansion and wheel assemblies were functionally tested. Testing was typically defined by rotating the components, in this case the roller spindle and wheel, at a speed representative of what it would see in service but for a longer duration.

The first step in assembling the bogies was to position the idler and driven truck assemblies on the layout area with the four wheels spaced and located as if they were on the curved steel rail. To verify the

spacing, a steel angle with precision dowel holes was used to connect the interior ends of both sides of the truck frames. With the truck assemblies properly positioned, equalizer pins were installed within the pin carriages. Next, the expansion assembly was positioned and oriented over the trucks and methodically lowered to engage and seat itself on the pins and supporting trucks. It should be noted that the pin geometry included a lug detail with a precision running clearance fit, which ensured the expansion assembly was centered on the trucks but complicated assembly due to the tight tolerance fit.

With the expansion assembly seated and secured to the truck assemblies the only major sub-assembly remaining to be installed was the drive machinery assembly.

Photo 7: Expansion Assembly shown being lowered onto Truck Assemblies at shop.

Photo 8: Expansion Assembly shown seated onto Truck Assemblies at shop.

Holes for mounting the drive machinery frame had already been drilled under CNC control, so, as long as the holes were properly located they could be used to secure the frame to the driven truck extension. Once installed, the drive frame was then shimmed, up or down, to fine tune the center to center distance between sprockets and time the chains. With the bogie fully shop assembled, the driven wheel was then elevated above the layout floor and the drive machinery was functionally tested at full speed in both directions but under no additional load.

The last remaining checks were in the form of measurements to verify that the machining process and assembly effort had produced a replacement bogie that met the required geometry in order to travel along a circular path. All assembled bogies were found to have met the requirements as outlined within the Contract Plans.

Replacement Bogies Field Installation

As one might expect, the first bogie to be shop assembled, tested and prepared for shipment was the first to arrive at Miller Park. The bogie would arrive by truck as three separate sub-assemblies, i.e. the expansion, driven truck, and idler truck assemblies. It should be noted that at this stage the drive machinery and frame were a permanent part of the driven truck assembly.

Each piece was removed from the truck by crane and blocked on cribbing located along the outfield plaza or adjacent to the staging area. Miscellaneous components and accessories would arrive separately packaged and marked.

To prepare for assembly, sub-assemblies and accessories were cleaned free of rust inhibitors and labeled to define their position and orientation at full assembly. Measurements were then taken, at the track beam level, to define the relationship between running rail and overturning rails for the purpose of calculating the required upper guide roller shim packs.

Trucks were then fitted with lifting lugs for the purpose of hoisting and equalizer pins were lubricated and installed within their respective truck carriage housings. With the sub-assemblies prepped, the respective

running rail, at track beam level, was lubricated where the truck wheels were intended to land.

Assembly at Track Beam:

To start, a particular roof panel was positioned for bogie installation and a wind keeper was installed on the opposite end of the roof panel for stabilization during jacking operations. In addition, prior to any hoisting, wind and weather forecasts were verified to confirm installation would occur within specified tolerances and conditions.

Next, an idler truck assembly (approx. wt. = 33.5 kips) was hoisted 150 feet above the plaza level and positioned above its respective running rail. The truck was then oriented to compliment its installed position and slowly lowered onto the running rail. Portable jacks were then used to brace the truck assembly against the overturning rails. The truck was then centered on the running rail and secured in a vertical position. The lifting lugs were then removed, flown down to the staging area (outfield plaza level) and used to attach to the driven truck assembly.

In similar fashion the driven truck assembly (approx. wt. = 48.4 kips) was hoisted and positioned above its respective running rail adjacent to the idler truck assembly. The truck was then oriented to compliment its installed position and slowly lowered onto the running rail. Additional portable jacks were then used to brace the truck while it was centered and set vertical. Once secure, the lifting lugs were removed and flown back down to the staging area for use on the next bogie. With the lifting lugs removed, horizontal guide rollers and shims were installed at each of the designated mounting locations so that most of the portable jacks could be removed. The truck assemblies were then temporarily connected with fabricator supplied alignment and spacing angles to ensure proper alignment between truck assemblies.

With alignment verified, the expansion assembly (approx. wt. = 42.5 kips) was hoisted using nylon straps and positioned above the truck assemblies. The equalizer frame was then oriented to compliment its installed position and slowly lowered until nearly seated on the truck equalizer pins. The remaining hydraulic jacks and spacing angles were then removed; allowing the trucks to “float” and the expansion assembly was fully seated on top of the supporting pins.

Photo 9: Expansion Assembly being hoisted from plaza level to track beam.

Photo 10: Expansion Assembly being aligned with trucks at track beam level.

And finally, to complete the attachment between the expansion and truck assemblies, each end of the two equalizer pins were provided with an equalizer pin ring, elastomeric washer, and end plate.

Installation at Track Beam:

With the bogie fully assembled at the track beam level it was now ready for installation. In order to install the replacement bogie, the roof load had to be transferred from the original bogie to a temporary jacking and supporting system. The sequence of installation was as follows:

- lift roof panel corner 6 to 8 inches

- secure hydraulic jacks with locknuts
- drive original bogie out from under panel under electric power
- attach rigging to existing lifting lugs on original bogie frame
- lift original bogie clear of guide system and lower to plaza level
- connect power to replacement bogie motor
- slowly drive bogie into position under roof panel
- release locknuts from hydraulic jacks
- lower roof panel until it is ½ inch from contacting roller spindle
- final align bogie relative to roof panel expansion plate
- lower roof panel completely onto replacement bogie

These steps were then repeated nine (9) more times in the effort to replace all ten original bogies. The installation effort required the panels to be located in multiple positions, which meant they had to be kept operable in order to minimize the hoisting and jacking locations at the plaza and track beam levels. The installation effort was completed just before January 2007.

Commissioning

The commissioning effort was extensive. Up to this point much of the focus was on installing the replacement bogies prior to the arrival of the harsh Milwaukee winter period. And because the winter was just setting in, it was decided that to ensure proper installation, some of the effort would take place during the early part of the baseball season.

The effort involved integrating new programming and controlling equipment as well as fine tuning the position of upper and lower guide rollers for proper interaction with the rail systems. Although the efforts were not overly complicated, they had to be performed at ten (10) locations, under reduced operating speed, and over 2100 linear feet of operating distance.

By June 07, all five (5) panels were fully tested and given the green light to operate automatically at full speed. Since the replacement work, it is estimated that the roof panels have moved opened or closed 340 times, averaging 170 moves per year. With all ten bogies replaced at the running end and all five pivot bearings replaced by 2003 at the pivot end, the retractable roof mechanisms have been replaced in their entirety with new, upgraded components that continue to operate well. And although it has been a long and arduous road for those involved with the planning and construction efforts at Miller Park, they are finally in a position where they can close the chapter on retractable roof problems.

Acknowledgements:

Miller Park – Closing The Chapter On Retractable Roof Problems

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