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Technical Article

High-Performance Spherical Roller Bearings:

Meeting Today's Greater Demands

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- Demonstrated load rating increase; testing shows lower operating temperatures, longer life vs. leading designs

Abstract

Spherical roller bearings provide for precise, repeatable motion and reliable extended operation in the world's most demanding industrial applications. **Timken® High-Performance Spherical Roller Bearings** were designed as a stronger response to today's tougher environments and the increasing requirements of heavy industry.

This paper explores new expectations for key applications, advances in spherical roller bearing technology, and the design and testing of Timken high-performance spherical roller bearings, which meet published data for **increased dynamic load rating** and **superior thermal performance** compared to previous designs.

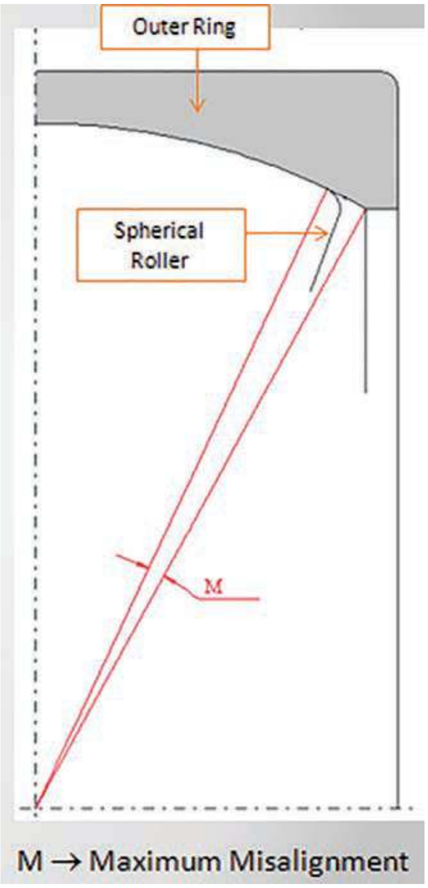


Figure 1:
Due to the spherical shape of the outer ring geometry, spherical roller bearings can maintain full bearing capacity with as much as 2° of misalignment produced by a combination of initial component alignment and dynamic deflections; their contact geometry also eliminates edge loading typical of other bearing types.

Market Demands

Today, industry expectations push the limits of durability and production in heavy industry, putting traditional machine and component designs to the test. The global marketplace demands greater reliability at higher operating temperatures, loading and speeds, emphasizing increased efficiency every step of the way. For many, opportunity will come from incremental improvements to existing technologies rather than major advances—logic evidenced in the design of Timken high-performance spherical roller bearings.

As oil producers drill deeper and further offshore, as paper mills commission bigger and faster machines, as mining operations grow more remote and as construction faces more punishing conditions, plant and equipment operators increasingly look to suppliers and manufacturers to generate new operational efficiencies. Across industries, the goal is measurable gains in performance, productivity and profitability resulting from improvements to existing systems, processes and assets.

Timken, which has offered spherical roller bearings for more than 70 years, launched an intensive continuous improvement effort aimed to outpace escalating load, speed and temperature requirements for bearings operating in critical applications.

The Case for Spherical Roller Bearings

Spherical roller bearings are a special class of roller bearings, counted on in many of the most difficult, demanding applications. These self-aligning, double-row radial bearings are designed with an inner and outer ring and "barrel" shaped rollers separated by a cage, allowing for greater load-carrying capacity and dynamic angular misalignment ability compared to other common bearing types, including tapered and cylindrical.

Most bearings are intended to carry either a radial load (acts perpendicular to the shaft) or axial load (also called thrust load; acts parallel to the shaft). Spherical roller bearings, however, must tolerate combined loads where moderate-to-high radial and axial forces are at work (*Figure 1*).

Spherical roller bearings are used not only where shaft misalignments are common, but where contamination, shock and vibration also are constant challenges. Their robust design and higher tolerance for misalignment are especially suited to heavy machinery, industrial equipment and large gearboxes. Typical markets and applications include:

- **Pulp & Paper** (chippers/debarkers, calendar rolls, internal suction rolls, press rolls, dryers)
- **Power Transmission** (hoists/cranes, pumps, compressors, wheels, sheaves, winches, conveyors)
- **Gear Drives/Gearboxes** (high speed, marine, wind energy, general industrial)
- **Metals** (caster rolls, drives, pinion stands, crop shear drives)
- **Cement/Aggregate** (vertical rolling mills, jaw/impact crushers, vibrating screens, conveyors)
- **Construction/Mining** (shovels, trenchers, draglines, excavators, crushers, compactors, shearers)
- **Power Gen – Coal** (pulverizers, gear drives, pumps, draft fans, conveyors)
- **Oil/Gas** (mud pumps, drawworks, jackup drives)
- **Sugar** (mills, dryers, coolers, vibrating/rotary screens, pumps)
- **Other** (ropeways, presses, elevators, pellet mills, harvesters, shredders, wood cutters)

High-Performance Parameters

"High performance" relative to spherical roller bearings is described as an increase in bearing service life, which allows the potential to downsize other component selections while maintaining current levels of system performance (that is, smaller equipment and systems working more efficiently/effectively; increased power density translating to greater power throughput and longer system life).

High performance is also described as a reduction in heat generation; bearings that function at lower temperatures under demanding conditions create the potential for increased efficiency and speeds of operation. Lower temperatures reduce the oxidation rate and deterioration of oils, greases and films, extending lubrication and thus, bearing service life.

While the basic functionality of today's spherical roller bearings remains fundamentally similar to that introduced in the 1950s, continuous improvements to performance have been a focal point for bearing manufacturers. The research and development effort from Timken progressed with the market to exceed the growing size and power requirements of heavy machinery and gear-driven equipment.

Figure 2:
The Timken high-performance spherical roller bearing.

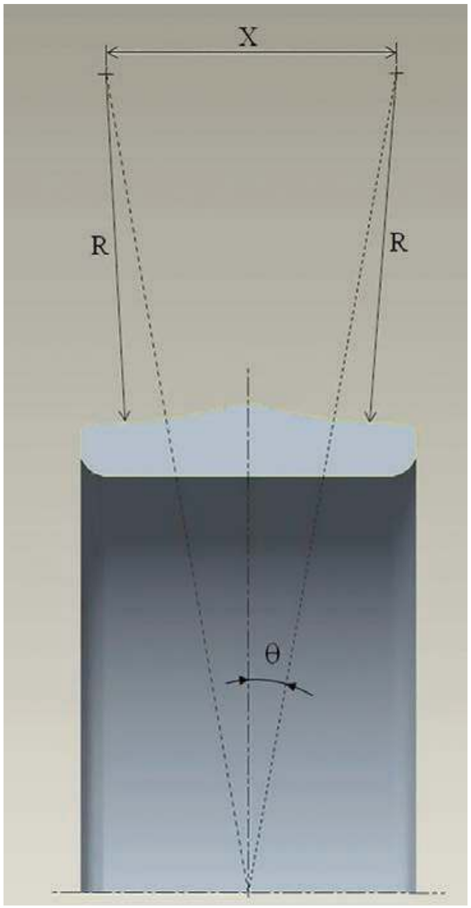


Figure 3:
Spherical roller bearing inner ring geometry

Key Design Elements

Objectives for design optimization of the Timken spherical roller bearing (Figure 2) included: 1) greater load-carrying capability, 2) reduced operating temperature and 3) extended service life. Specifically, activities were focused around: 1) optimizing internal geometries to maximize roller length and dynamic capacity, 2) improving surface finishes to support higher ratings and increased lubrication lambda ratios, 3) strengthening cage design to reduce wear, 4) enhancing lubrication flow to rolling contact surfaces, and 5) improving heat dissipation.

As a standard element of any continuous improvement endeavor, Timken also set out to reduce design complexity where the potential for simpler and/or fewer components was presented.

The design of the new high-performance bearing follows the ISO standard for bearing boundary dimensions (inner diameter [I.D.], outer diameter [O.D.] and width), allowing for general interchangeability with other manufacturers. The standard does not, however, dictate cage design or internal geometry, which is where Timken high-performance spherical roller bearings derive their differentiated performance advantages.

Internal geometry

At the heart of spherical roller bearing design is the inner ring geometry (Figure 3), requiring both precise design specification and manufacturing consistency. The inner ring allows a complex interaction between the bearing contact angle and raceway profile[1], which must be specified to achieve the optimal combination of size and form to produce the most efficient raceway-roller dynamics (Figure 4).

Timken extended the demonstrated high-performance parameters of the Timken P900 tapered roller bearing—which has shown service life improvements in strenuous applications for nearly 20 years[2] to the new spherical design. P900 relies on optimized geometries, special finishes and high-quality materials to achieve an increased power density (bearing capacity to weight ratio) to provide a more efficient solution[3-5].

Specifically, advanced geometry virtually eliminates edge stress concentrations caused by high loads or misalignment. The macro raceway profile contact geometry was improved to minimize the opportunity to develop conditions where contact stresses are concentrated at one location

Figure 4:
High-performance spherical roller bearing component explosion highlighting inner ring.

thereby greatly reducing rolling contact fatigue life. Timken employs a multi-tiered method of assessing profiles. Figure 4a provides a typical result for a raceway profile trace assessment, relative to the high-performance design intent envelope depicted by the bold radii. Figure 4b predicts contact stress results for a profile trace versus the nominal design intent. Given the stress peaks that would result in premature life predictions, this profile would not be acceptable.

The micro raceway texture was also improved by reducing the composite surface roughness. This has a direct effect on increasing the operating lambda (λ) ratio (Figure 5), where lambda equals the predicted operating oil

Figure 4a:
Raceway profile gauge envelope.

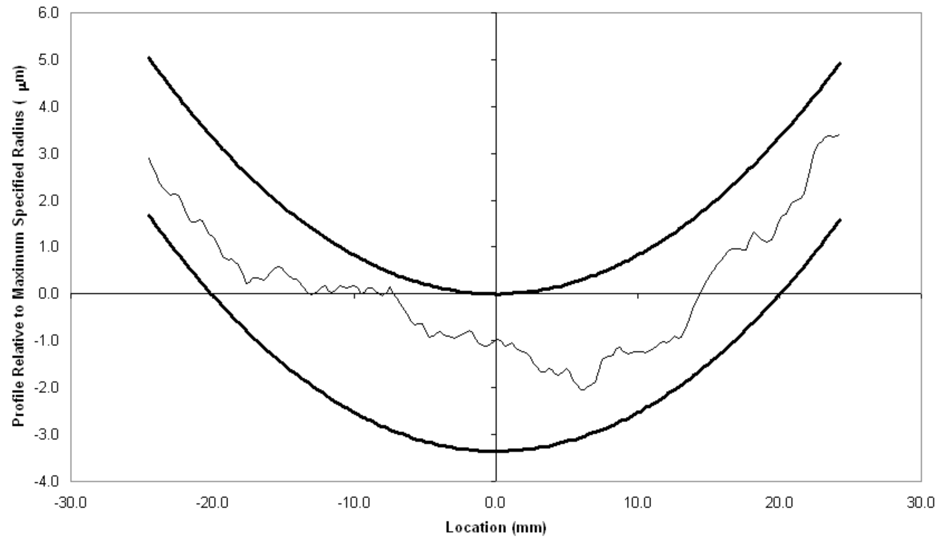
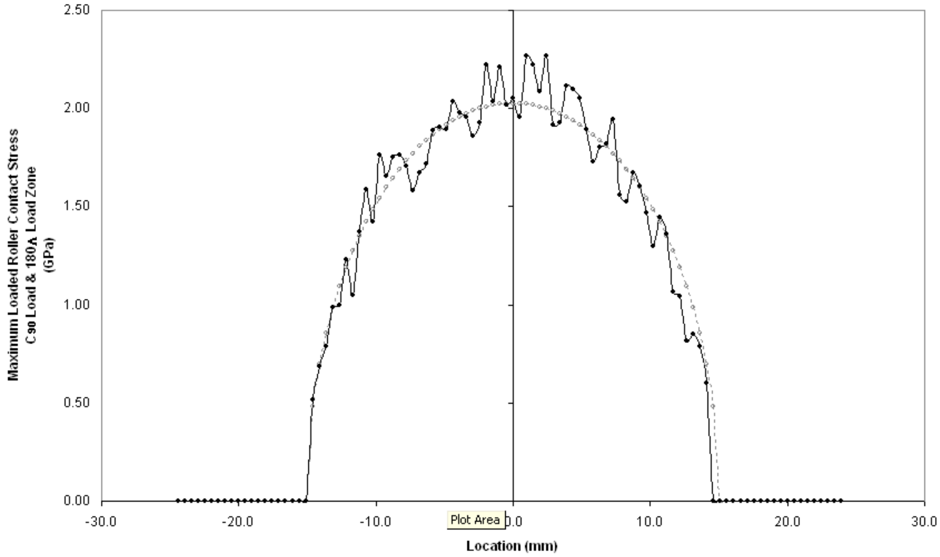


Figure 4b:
Stress profile assessment.



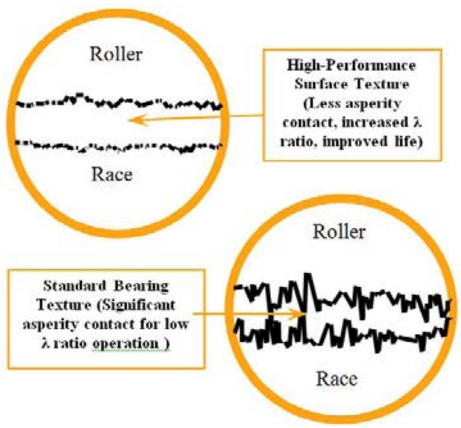


Figure 5:
Lubrication lambda ratio improvement.

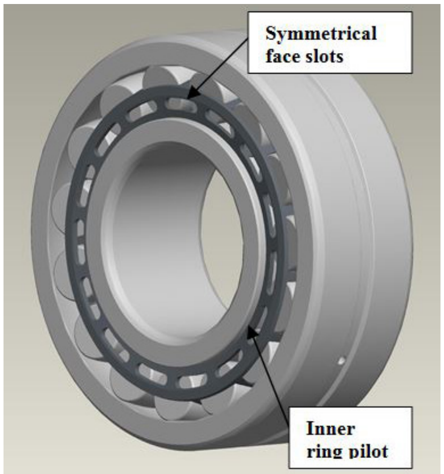


Figure 6:
Timken high-performance EJ assembly.

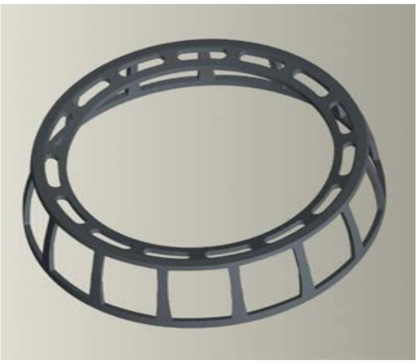


Figure 7:
EJ steel cage.

film thickness divided by the composite surface roughness. Improvement in lambda ratio has been well documented to increase bearing fatigue life predictions, as represented by a_{3l} factor increase in factor-based life calculations[6-8]. Specifications on micro texture were employed beyond those associated with composite roughness to ensure the desired lambda ratio is achieved in operation. The improvement in surface texture also sets the stage for potential reduced heat generation by allowing the selection of reduced viscosity lubricants that still meet adequate operating lambda ratios.

Cage construction

Cages (also called retainers) serve several purposes in the proper operation of a rolling element bearing, including separating the rolling elements to prevent roller-on-roller contact and wear. Cages also align the rolling elements on the inner ring outside the operating load zone to minimize roller sliding, skidding and skewing.

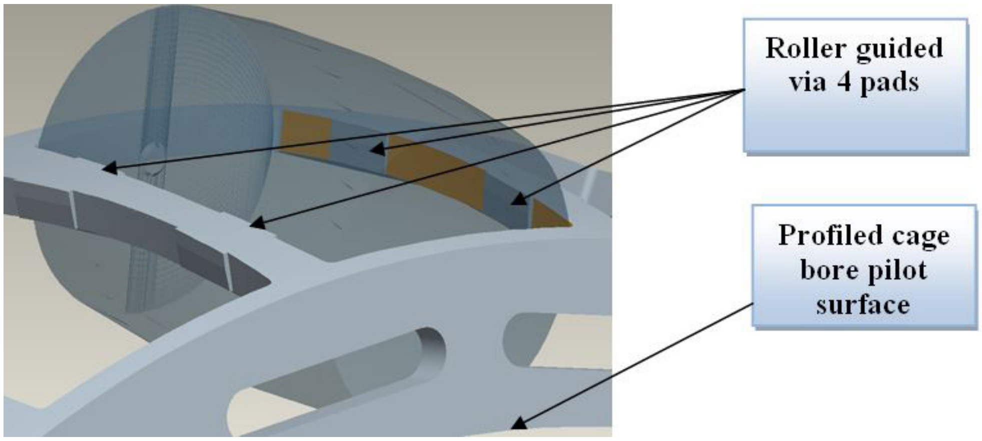
An advanced cage design methodology was incorporated into the Timken high-performance spherical roller bearing, resulting in the Timken EJ steel cage (Figures 6 & 7). At elevated speeds, a steel cage provides an advantage over brass due to its lower mass and reduced roller/cage contact. The EJ cage is also nitrided (surface hardened) for improved wear resistance and fatigue strength.

The new design incorporates the same positive aspects of existing Timken steel cages, including inner ring piloting, low mass, low inertia, an individual cage for each row, no separate center ring for roller axial positioning and introduces slots in the outboard face of the cage (Figure 6). The symmetrical openings are oriented between the cage pockets to facilitate lubricant flow in and out of the inner ring raceway. This helps to assure lubricant availability to these rolling contact surfaces to generate a satisfactory film while further reducing the potential for extreme heat due to viscous shear from excessive lubricant supply.

Cage guidance

The EJ design includes two independent cages (one for each row of rollers), which are assembled into an individual bearing. This allows each path of cage and rollers to operate independently. The window-style pocket construction reduces bending stresses. The cage is guided on the inner ring (opposed to roller guidance, which transitions loads to the rollers, generating more heat) and runs above pitch. This increases cage stiffness and reduces stress under high shock load or acceleration.

Figure 8:
Large EJ steel cage.



For bearings with an O.D. greater than 400 mm, the cage and roller mass can become substantial and negatively impact bearing heat generation and operating temperatures. To counter this, the bore of larger EJ steel cages is specifically profiled to minimize friction and associated heat generation from contact with the inner ring pilot surface.

Roller guidance

Rollers are guided by the edges of the cage pocket for smaller bearings (<400 mm O.D.). For larger sizes, the pocket is contoured with four pads (strategically located on the bridge surface) that contact and orient the rollers coming into and out of the bearing operating load zone. This interaction minimizes potential for negative roller skew and its associated increase in friction torque and operating temperature (Figure 8).

No central guide ring

Given these precise cage pocket interactions, a central guide ring is *not* required to axially position the rollers in the EJ design. Without a guide ring, the friction generated between the rollers and ring is eliminated, equating to cooler running bearings. Less friction also means less energy is needed to move the bearing initially and to keep it moving.

Eliminating the guide ring further creates extra space within the design envelope to accommodate longer rollers, meaning increased load capacity. Alternatively, lubricant flow between the roller paths is improved by increasing available void volume.

Thus, the EJ cage pocket design can translate to reduced bearing operating temperature and running torque in applications where central ring-guided spherical roller bearings are currently used.

Note: Roller/cage interface design optimization was also performed on Timken brass cage offerings (EM and EMB). Brass cages are more resistant to extreme loads and shock (meeting the demands of vibrating screen and high-speed planetary gearbox applications, for example). They are also suited for low-lubrication conditions due to the dissimilar material of the rollers and cage. Cage fingers provide constant, precise roller guidance.

Design Validation

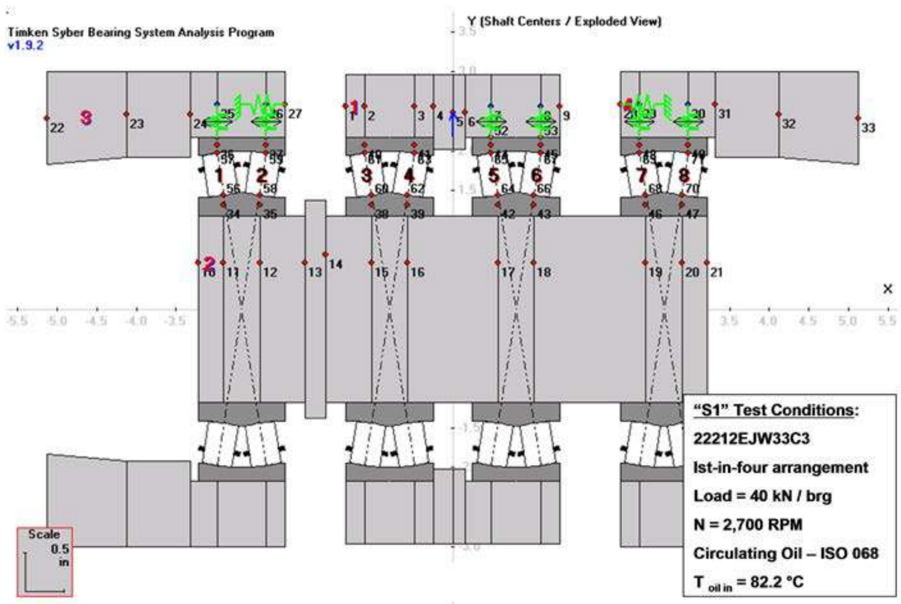
Validation of the Timken high-performance spherical roller Bearing design was extensive in order to meet the stringent requirements of Timken brand products. This included standardized fatigue life testing to confirm durability under strenuous and accelerated operating conditions, as well as testing on different platforms to verify bearing heat generation response as measured by outer-ring temperature. An assessment of competitive high-performance products was also completed, and the results compared to the Timken high-performance spherical roller earing. Specifically, testing sought to: 1) Substantiate an increased dynamic load and thermal speed rating over previous Timken spherical roller bearings and 2) Validate a lower operating temperature and longer service life compared to other leading high-performance designs.

Methodology and modeling

Timken standard life testing is completed in a first-in-four arrangement (Figure 9). The bearings are tested under an elevated load and speed condition using a circulating oil lubrication system that controls the inlet oil temperature to a specified elevated level. The intent is to test the bearing rolling contact surfaces in an accelerated manner relative to surface and subsurface fatigue modes. The influence of bearing design, material, heat treatment, geometry, surface profile and texture have a combined impact on life testing with the first-in-four format used to develop the test Weibull statistics.

Timken SYBER analytical modeling software is used to establish the predicted bearing performance based on the bearing metrology and test conditions. Test results are evaluated using Weibull statistics regarding L15.91 life and the associated 65 percent confidence bands to establish test performance. The Weibull result is then compared to the SYBER predictions, and an assessment is made regarding acceptability of the resultant life ratio. These ratios are reviewed to determine their degree of support for intended rating performance levels.

Figure 9:
SYBER modeling of life test arrangement.



Life testing

Validation life testing consisted of a number of bearing test populations spread across four basic size and series designs. For each, individual groups of a minimum of 24 bearings were run using the accelerated testing format. Multiple groups were run for each size, and in total, 27 groups (more than 592 individual bearings) were tested as summarized in Table 1. Monitored parameters included vibration, temperature, torque, bearing condition and duration.

For each of the four spherical roller bearing series tested, SYBER was used to establish predicted life for given conditions. The Weibull results were then divided by the SYBER predicted fully adjusted lives, with a dynamic load rating calculated per ISO 2819 to produce the ISO Life Test Ratios (summarized in Figure 10). A Life Test Ratio of 1 indicates product performance barely supports the prediction when a basic ISO 281 dynamic load rating is used. It can be seen here that all groups' Life Ratios exceed 2.5, and the LCL65 limits exceed 2 for all conditions. This is required if the product is to be deemed "high performing" with an associated increased dynamic load rating. Testing sought to substantiate product performance and produce data to support an increased dynamic load rating. Figure 11 shows the High-Performance Life Test Ratio after the bearing dynamic load rating is increased, this time using the Timken rating methodology2; 10 as the base. It can be seen that all Life Ratios are greater than 1, and most are 2 or more. The lower confidence bands are also significantly greater than 1, indicating high confidence in an increased load rating of this magnitude.

Competitive life testing

The validation plan also included a competitive benchmarking component. Three top-tier spherical roller bearing designs were selected for comparative testing (for each, the competitor's explicitly stated "high performance" offering was chosen). A life test program consistent with bearing size 22212 was completed and the results compared (Figure 12). The competitive life ratio was established by dividing the life test results of the individual group by that of the Timken results.

Table 1:
Life and Durability Testing.

SPHERICAL ROLLER BEARING – LIFE AND DURABILITY TESTING

Test Objective: Develop statistically valid results of bearing life performance.

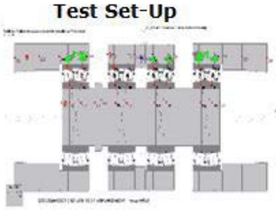
Typical Test Conditions

- Test Method: First-in-Four
- Bearings Tested per Test: 24
- Load: ~30% of bearing dynamic rating
- Speed: ~30% of limiting speed
- Lube: ISO 068 oil (Recirculating w/40µm Filter)
- Inlet Oil Temp: 82.2ºC (180ºF)

Monitored Parameters

- Vibration
- Temperature
- Torque
- Bearing condition
- Duration

Test Set-Up



Testing Summary

Bearing Size	# of Tests	# of Bearings Tested	Revolutions (millions)	Cumulative Test Hours*	Cumulative Elapsed Time* (years)
22212	11	264	7,760	47,899	5.5
22216	8	192	2,710	37,639	4.2
22322	5	64	1,874	26,025	2.9
23048	3	72	436	14,535	1.7
4 sizes	27 tests	592 bearings	12,780m revolutions	126,098 hours	14.4 years

*Cumulative elapsed time shown is the sum of the time to complete each test. Multiple tests ran simultaneously.

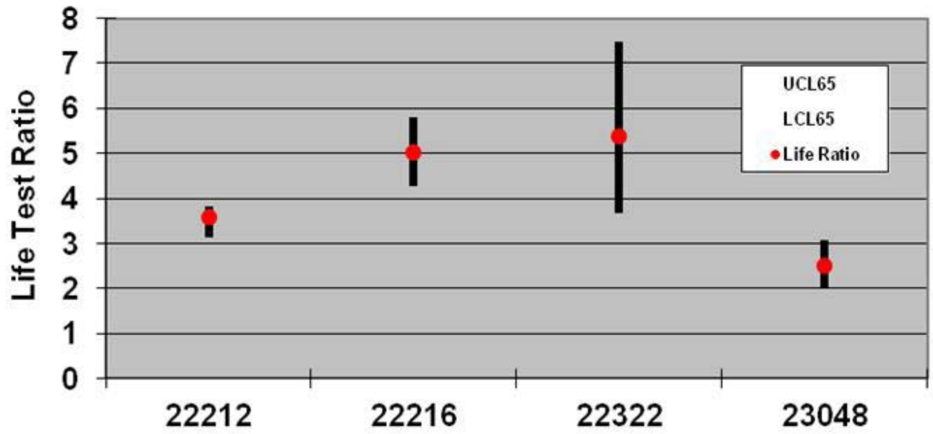


Figure 10:
ISO Life Test Ratio for four basic test group sizes.

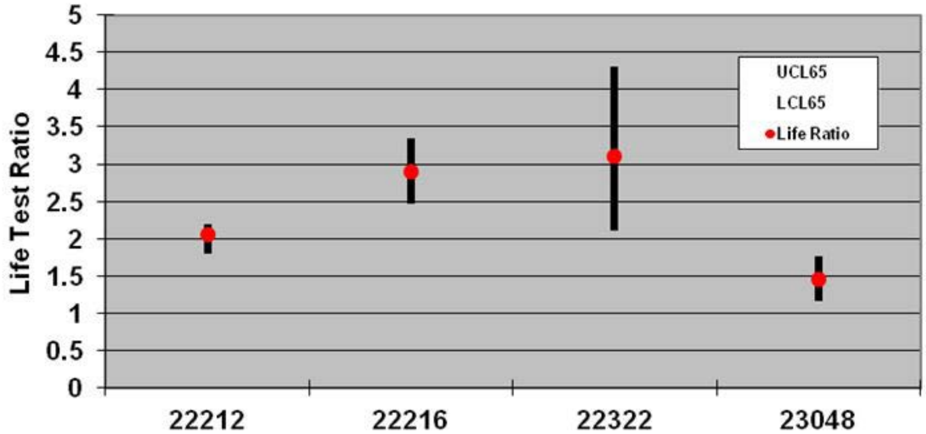


Figure 11:
High-Performance Life Test Ratio for four basic test group sizes.

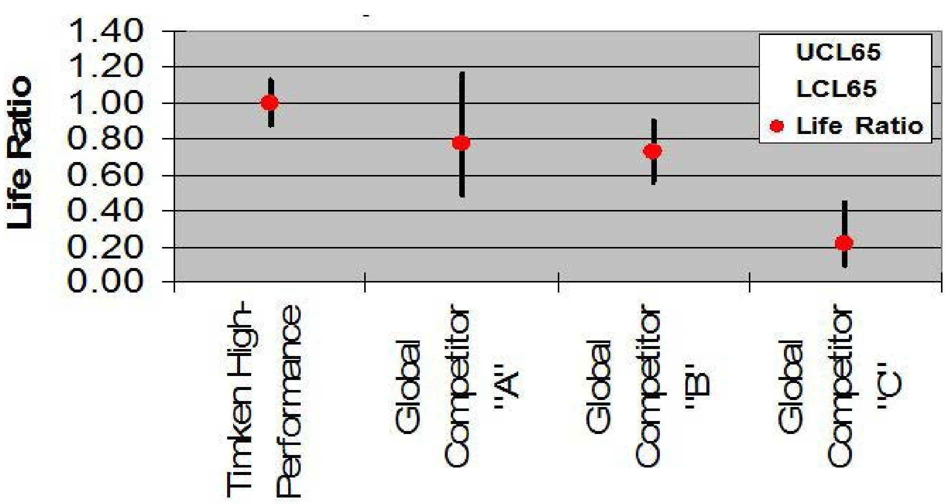


Figure 12:
Competitive Life Testing for 22212.

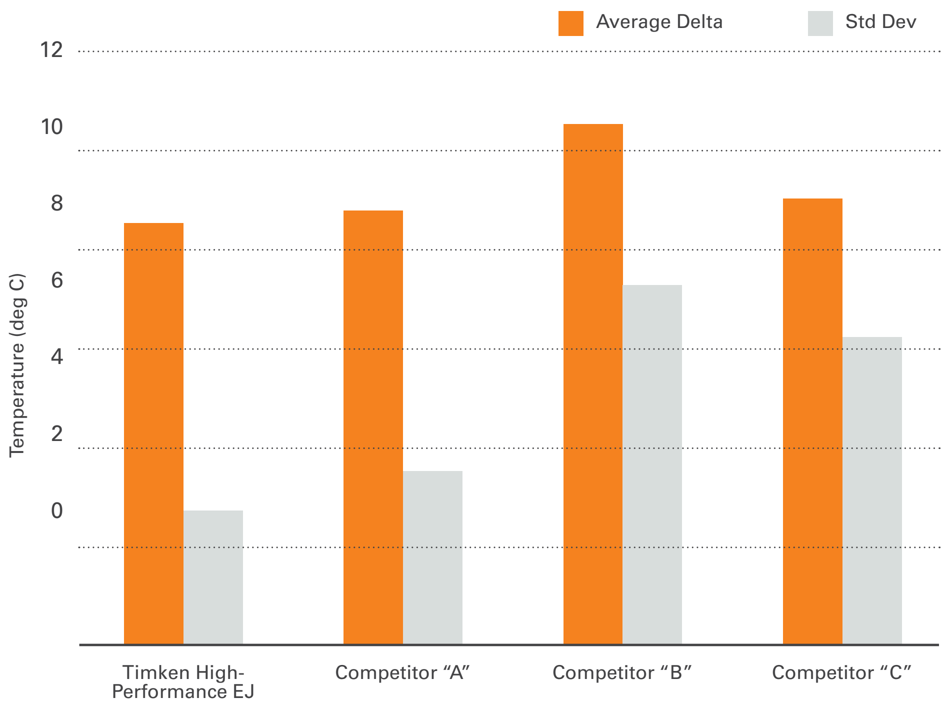
Each of the competitive products was assigned an enhanced dynamic load rating compared to ISO 281 calculations[9]. As shown in Figure 12, it is clear that not all spherical roller bearings categorized as "high-performance" perform to the same level. All competitor life ratios are less than 1, and assessment of the 65 percent confidence bands indicates statistically significant differences between some competitive designs and the corresponding Timken design. The larger size of the bands also indicates greater variation in the populations for the competitive products.

Heat generation testing

Figure 13 shows the results if this same life test data is evaluated from a thermal perspective via operating temperatures. The outer ring O.D. temperature was continuously monitored for each bearing during operation. Of note is the difference or "delta" between the inlet oil temperature and bearing O.D. temperature. The Timken high-performance spherical roller bearing consistently operates with the lowest average temperature and has the smallest standard deviation. This is consistent with reduced operating variation and reduced likelihood of elevated operating temperatures, which can dramatically impact bearing life due to reduced lubrication lambda ratios.

A second aim of heat generation testing was to assess the life test arrangement with a combined radial and axial load condition. Radial loads were applied in the conventional manner through the center bearings, while axial loads were applied to the end of the outboard bearing housings. This produces a combined radial and axial loading condition on the outboard end bearing positions, and maintains a pure radial load on the center bearings.

Figure 13:
Life test operating temperature comparison.



The test matrix (Table 2) consists of three different load levels (defined by increasing the radial equivalent load to decrease the capacity to load ratio), with four combinations of axial to radial load ratio (producing the same radial equivalent load). Each bearing arrangement was operated through four increasing speed conditions (1200, 2400, 3600 and 4800 rpm) for each of the 12 load steps. This combined matrix produced 48 load and speed steps for assessment of bearing operating temperature.

Table 2:
22212 Combined load heat generation test plan.

BDLR :	169	kN	"e"	"X1"	"Y1"	"X2"	"Y2"
			0.24	1	2.84	0.67	4.23

Radial Equivalent Load (P_{eq}):

T/R <= "e", P_{eq} = R*X1 + T*Y1
T/R > "e", P_{eq} = R*X2 + T*Y2

BDLR / P_{eq}	P_{eq} kN	"T/R" = 0 Radial kN	"T/R" = 0 Thrust kN	"T/R" = 0.12 Radial kN	"T/R" = 0.12 Thrust kN	"T/R" = 0.24 Radial kN	"T/R" = 0.24 Thrust kN	"T/R" = 0.36 Radial kN	"T/R" = 0.36 Thrust kN
		("1")		("2")		("3")		("4")	
12	14	14	0	10.45	1.25	8.34	2	6.36	2.3
		("5")		("6")		("7")		("8")	
8.45	20	20	0	14.9	1.8	11.9	3	9	3.3
		("9")		("10")		("11")		("12")	
4.84	34.9	34.9	0	26	3.1	21	5	16	5.7

The bearings were lubricated by a circulating oil system, providing a nominal 0.95 l/min oil flow per bearing, and the 37.85 liter oil sump was allowed to seek its own stabilized temperature based on total system heat generation. The system was allowed to operate until thermal equilibrium was obtained, based on stabilized operating temperatures. The results for average O.D. temperature are summarized in Figure 14.

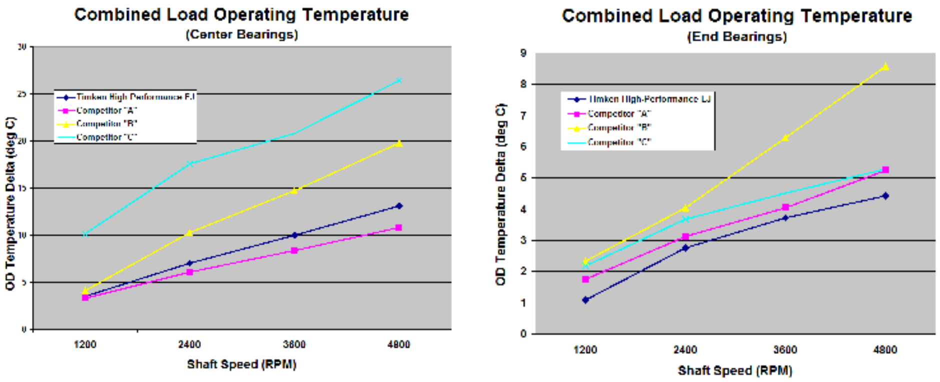


Figure 14:
Combined load test temperature results, end and center bearings.

The Timken hgh-performance spherical roller bearing produced superior results while operating the coolest for the demanding combined load end positions. Consistent with the life test temperature results, Competitor B produced the highest operating temperatures, while Competitor C experienced particularly elevated temperatures for the center bearing positions. Thus, the test suggests longer service life for the Timken bearing as a result of reduced operating temperatures.

Vibratory screen testing

The final intent of the heat generation assessment was to validate operation on a vibrating screen platform. A horizontal test unit utilizing a two-shaft, four-bearing arrangement was operated at 865 RPM, which produced an inertial loading of 10 g-force. The unit was operated in its design splash lubrication scheme using Mobil Spartan EP 150 gear oil, and system thermal response was monitored during 400 hours of operation. Figure 15 provides a graphical comparison for the Timken high-performance spherical roller Bearing compared to competitor designs.

As confirmed by infrared thermography (Figure 16), distinctive temperature profiles develop during the test. The operating pattern for the Timken bearing is shown compared to a competitive arrangement.

Figure 15:
Bearing O.D. temperature comparison for vibratory testing.

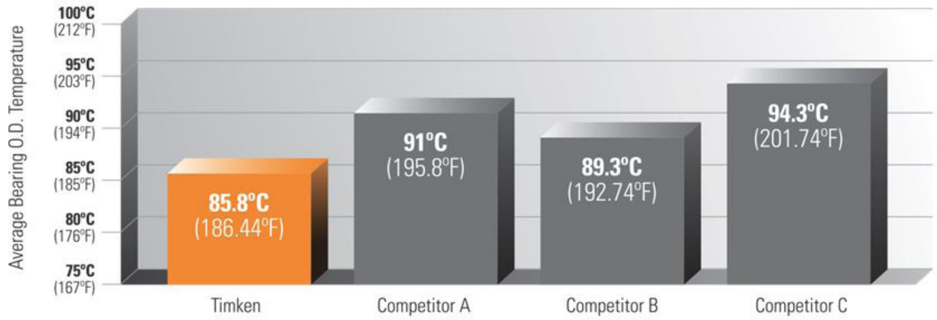
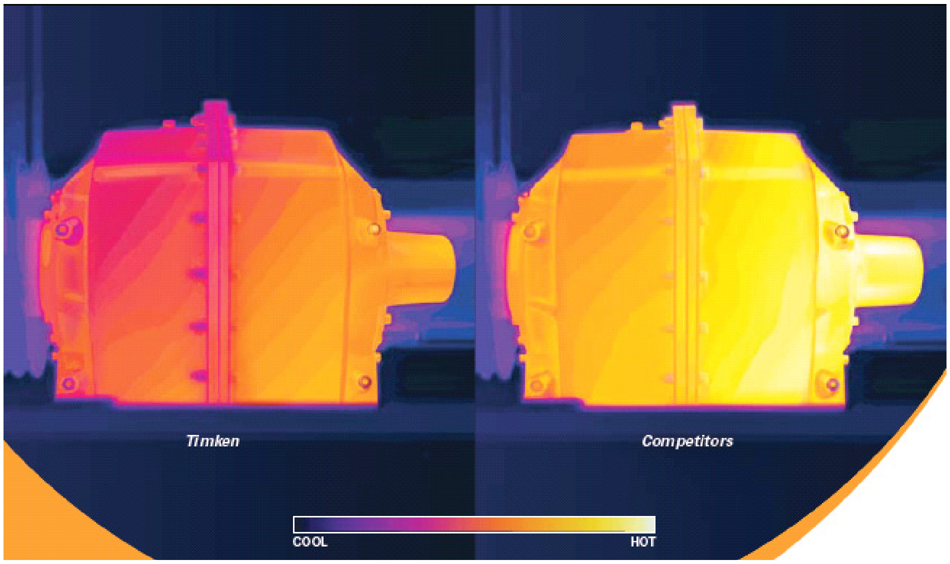


Figure 16:
Infrared thermography of vibratory testing.



Graphic representation of thermographic readings in a typical industrial setting based on actual test results.

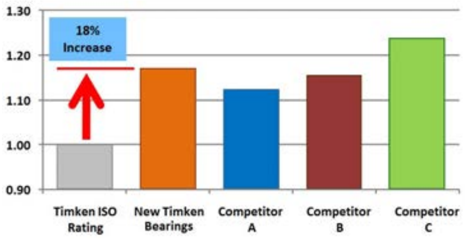


Figure 17:
Load rating comparison – average of 222 series.

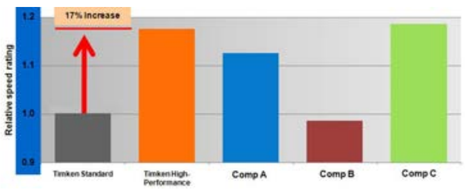


Figure 18:
Thermal speed rating comparison – average of 222 series.

There is a clear and substantial difference, translating to cooler operation with the associated improvements in predicted bearing and lubrication service life.

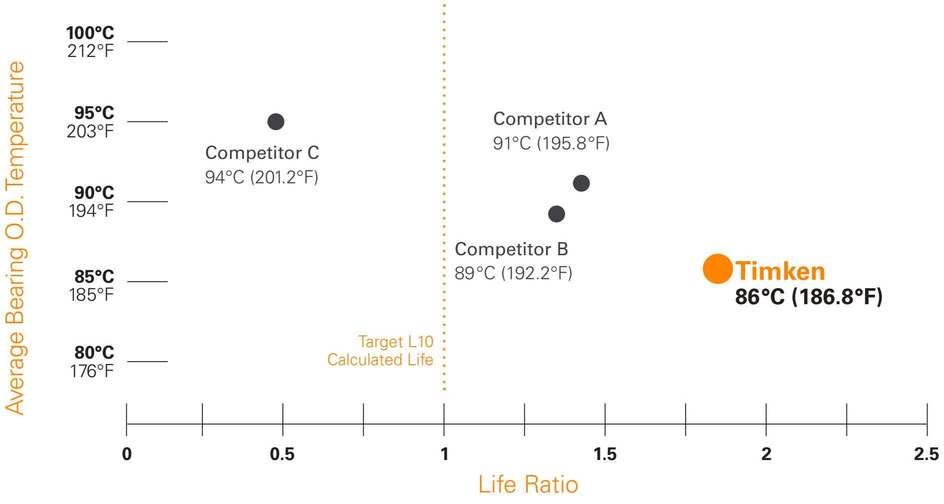
The Timken Difference

Validation results were consistent and conclusive; the **Timken high-performance spherical roller bearing** achieved its performance targets. An **increased dynamic load rating of 18 percent** was substantiated (Figure 17), and a **17 percent thermal speed rating increase** confirmed (Figure 18), relative to previous Timken spherical roller bearing designs.

Side-by-side application testing under identical loads, speeds and lubrication conditions further showed the Timken bearing achieved a **longer calculated life** and **ran between 3° C and 8° C cooler** than leading competitive high-performance designs (Figure 19). Of significance to machine and equipment owners and operators is that a 5° C decrease in operating temperature can equate to a 9 percent increase in bearing service life.

The results validate a high-performance spherical roller bearing design that is ready to meet the escalating load, speed and temperature requirements of heavy duty industrial machines and equipment. Ultimately it is efficient, reliable performance that equates to increased uptime and lower operating costs in the world's most demanding applications and environments.

Figure 19:
The Timken bearing demonstrated a lower operating temperature and longer life compared to competitive designs.



Tested 22212 at 2700 rpm with a load ~25% of the dynamic capacity.

For any product to be backed by the Timken brand, the test results must be substantiated for all involved production supply chains, and quality manufacturing processes capable of consistently achieving high performance must be demonstrated. This was accomplished by multiple-year evaluations of the total Timken high-performance spherical roller bearing supply chain, which confirmed that specifications and procedures are in place to ensure production will support the Timken brand promise.

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