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THE TIMKEN ADAPT™ BEARING FOR SLAB SUPPORT ROLLS IN CONTINUOUS CASTERS[1]

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Abstract

This paper describes the design, operating principles, design validation tests and field test results for a new type of bearing initially targeted for use in the float positions on slab support rolls in a continuous caster. This is an extremely challenging application for rolling element bearings. Speeds are low while loads are high. Misalignment capability of up to 0.5° is required and float positions must be able to accommodate roll axial growth of up to 6 mm due to the thermal operating conditions. While spherical roller bearings [SRB] perform well in fixed positions, the float position continues to be a challenge. Attempted solutions to date have included an SRB that floats in its housing, cylindrical roller bearings [CRB] with aggressive profiles, CRBs incorporated within a spherical bushing and toroidal roller bearings. All of these solutions have met with some degree of success but all have had limitations or disadvantages too. The Adapt bearing was designed specifically to address the limitations of the existing designs and is a completely new bearing configuration. The bearing offers the axial float capability of a CRB and similar misalignment capability to a SRB. This is accomplished in a typical bearing assembly of two rings and a complement of rollers. A key feature is that the two capabilities are independent of each other i.e. axial float does not affect the bearings ability to misalign and vice-versa. Handling and installation can be facilitated by the separable inner-ring and by the unitized roller and retainer assembly.

Key words: Caster; Segment; Bearing; Roll.

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1 INTRODUCTION

Today, the Continuous Caster is the primary production process for steel slabs, blooms and billets and nearly 90% of the world's finished steel is produced this way. In 1970 the number was just 4%.(1)

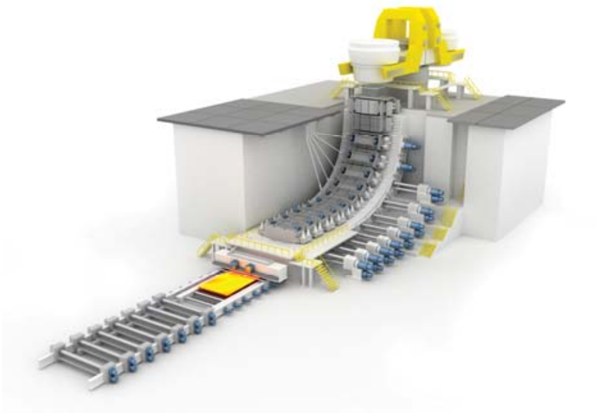

Figure 1. Typical slab caster layout.

There have been countless developments in the design of these machines over the last sixty years that touch all aspects of their operation. This paper addresses a new development in bearing design that is aimed at the float positions on slab support rolls in the bender, bow, straightener and horizontal segments of Continuous Slab Casters.

2 THE APPLICATION

After a continuously cast strand leaves the mould it must be carefully supported in order to maintain its shape and the thin and fragile solid skin. The prevailing method of providing this support is by rollers – these rollers are positioned on all four faces of the slab immediately beneath the mould but only on the top and bottom [wide] faces in the segments below this point. The rollers in the first segments are smaller in diameter than those further down the machine to allow them to be positioned close together to provide the required support to the slab. Further down, wider spaced and larger diameter rolls can be used because the cast slab cools and gains strength as it moves through the segments.
The design of the slab support roll assemblies continues to be a challenge. This is not surprising upon observation of the current operating environment and design requirements of the rolls:

- Intimate contact with a red hot slab at temperatures as high as 900°C;
- internal cooling;
- operation under a constant flood of external cooling water and steam that is contaminated with scale;
- accommodation of significant thermal axial growth – up to 6 millimeters;
- loads on the rolls are high – up to approximately 100 tonnes. Roll deflection must, however, be held to a minimum;
- rotation at low speeds between 1.5 RPM and 15 RPM depending on diameter and slab speed;
- driven rolls must transmit the drive torque across their full face width;
- assemblies must be serviceable and re-buildable.

Roll assembly designs vary between caster suppliers but, from the bearing supplier's perspective, share many commonalities. The design variations are numerous but slab widths and therefore roll lengths are such that all rolls need intermediate support bearings across their width in order to minimize deflection. The provision of intermediate support positions is achieved in various ways depending on the basic roll configuration. One design features separate short roll assemblies mounted in-line to provide the required overall width. Each separate roll section features one fixed and one float bearing. A wide roll assembly comprising 3 sections would therefore require six bearings (Figure 2). When used in a drive roll position the roll sections are mechanically coupled between the bearings.


Figure 2. Segmented Roll.

Alternately, a narrower roll assembly of the through-shaft design would require a bearing at each end plus one central support position bearing for a total of three bearings (Figure 3).

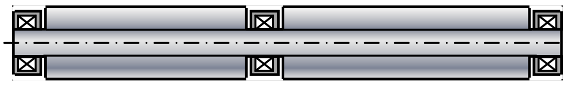
Figure 3. Through Shaft Roll.

The resulting large number of bearings and their performance in the caster is therefore very significant to the operator in terms of cost and reliability. The challenge to the bearing supplier can be distilled down to providing float position bearings that:

- Have a high static radial capacity within compact dimensions. Static capacity is the consideration because of the low rotational speed. They must be compact in width, to minimize the amount of unsupported slab, and outside diameter, to allow both a robust housing top section and maximum housing to slab clearance;
- can accommodate misalignment of 0.5° resulting from the roll and support frame deflections not only during normal operation but during periods of overload;
- have an axial internal float capability of plus or minus 6 millimeters to accommodate thermal axial growth of the roll;
- tolerate operation with little or no elastohydrodynamic lubrication film thickness because of the low rotational speed;
- are easy to install, remove and inspect.

The internal cooling of the rolls and bearing housings together with external cooling of the slab and rolls results in bearing operating temperatures that are only moderately high at 80°C to 90°C during normal operation. Special considerations relating to the operating temperature are limited to using a higher than standard radial internal clearance and, sometimes, using bearings that are dimensionally stabilized to a higher temperature than the standard 150°C.

2.1 Existing Bearing Designs

The spherical roller bearing [SRB] performs well in fixed positions and is almost always the bearing type chosen here. However, the float position bearings have

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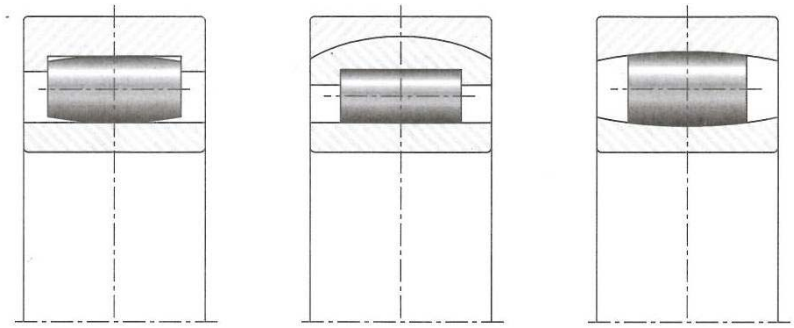
always been a challenge. Earlier designs used SRBs that were allowed to float in their housings but this was not ideal – it takes a considerable axial force to move a bearing that is under a high radial load. This introduces exaggerated non-uniform reactions in the bearing. The SRB does, however, accommodate static and dynamic misalignments well. The main alternative bearing types that have been introduced in attempts to provide a solution are:

- Cylindrical Roller Bearings [CRB] with aggressive roller and/or raceway profiles (Figure 4a);
- CRBs incorporated within a spherical bushing. These are generally referred to as Self Aligning Cylindrical [SAC] bearings (Figure 4b);
- Toroidal bearings (Figure 4c).



(a) (b) (c)

Figure 4. (a) CRB; (b) CRB within a spherical bushing; and (c) toroidal bearing.

All of the attempted solutions have been met with some degree of success but all have limitations or disadvantages as well. With respect to bearing type, problems range from limited misalignment capability to difficulties with installation and removal. The ideal bearing needs to combine the axial float characteristics of a CRB and the static and dynamic misalignment characteristics of an SRB together with simple construction and ease of handling.

2.2 The Timken Adapt Bearing

The Adapt bearing has been designed specifically to address the limitations of the existing designs and is a completely new bearing configuration. The bearing offers the axial float capability of a CRB with similar misalignment capability of an SRB. A key feature is that the bearing's abilities to accommodate float and misalignment are independent of each other. Specifically, the bearing's axial float position does not affect the ability to misalign and vice-versa. This is accomplished with a typical configuration of two rings and a complement of rollers. Load capacity is not compromised by the interaction of these two operating conditions. An additional benefit is that the full complement version for caster applications features a unitized roller and retainer assembly.

2.3 Basic Design

The design combines a cylindrical inner-ring ring with innovative profiled rollers and outer ring. The configuration is shown in Figure 5.

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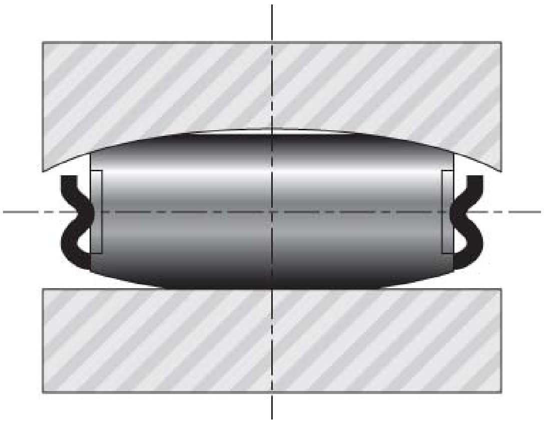

Figure 5. The ADAPT Bearing.

The combination of these profiles results in what can be described as 'three point contact'. Specifically the inner-ring to roller contact occurs at a single location while the roller to outer-ring contact occurs at two separate locations. The outer-ring contacts are symmetrically disposed at either side of the inner-ring contact, which leads to inherently stable roller dynamics. The mechanics of each contact point follow established design practice.

2.4 Bearing Operation

During centered and aligned operation the loads and reactions are balanced as represented in Figure 6. It can be seen that axial movement or float of the plain inner-ring has no affect on the load distribution – just as in an NU type CRB.

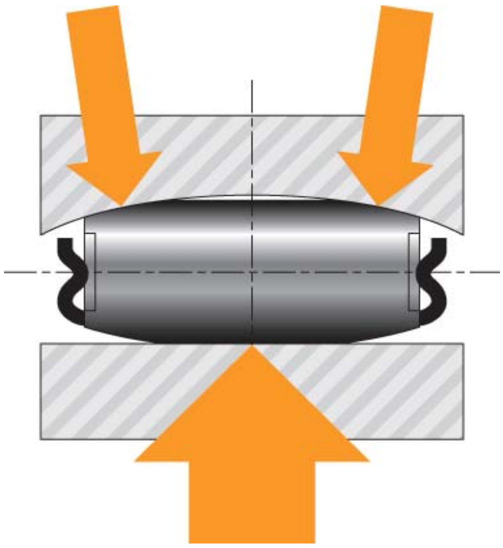

Figure 6. Aligned and Centered Condition.

When an angular misalignment is introduced the initial roller to outer-ring reactions become imbalanced – the load increases at one end of the roller and decreases at the other end as represented in Figure 7.

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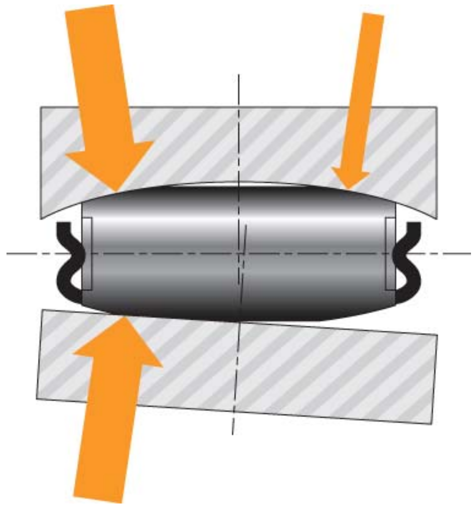

Figure 7. Initial Misaligned Condition.

Since the roller will always seek to balance the loads the axial component of the higher loads drives the roller over until the loads are again balanced and stability is re-established (Figure 8).

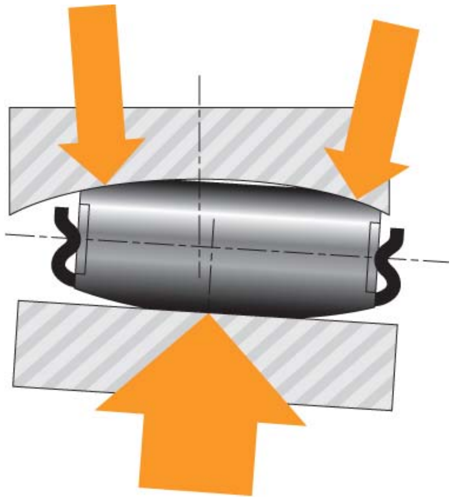

Figure 8. Balanced Misaligned Condition.

Roller and raceway surfaces have enhanced surface texture to maximize the load bearing surface area. The low level of surface finish also increases the relative oil film thickness [lambda ratio] in applications where there is sufficient rotational speed to develop an elastohydrodynamic lubricant film.

The bearing retainer allows for a full complement of solid rollers to be used while containing them in a single removable assembly. When combined with the separable inner-ring it results in a bearing that is straight forward to install, remove and inspect. Depending on the caster roll design the inner-ring can be installed separately on the shaft while the outer assembly is installed in its housing. Installation is further eased by interchangeable inner-rings because it is not necessary to keep specific inner rings and outer assemblies together as matched sets.

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2.5 Contact Stress Distribution

Modeling of the contact stress distribution shows that the stress levels remain within design limits. It should be noted that the design limits are those that apply to static loading because of the low rotational speed.
Figures 9 and 10 show the traditional roller to raceway contact stress distribution at the inner-ring for applied loads equivalent to 25% and 50% of the bearings static load rating [Co].
Figures 11 and 12 show the unique stress distribution at the outer-ring for the same loads. Note that there are no edge stress spikes. It can be seen in Figures 10 and 12 how the outer ring contact stress distribution spreads along the roller length as the load increases. This characteristic allows optimum stress distribution and acceptable stress values to be maintained despite the high applied loads.

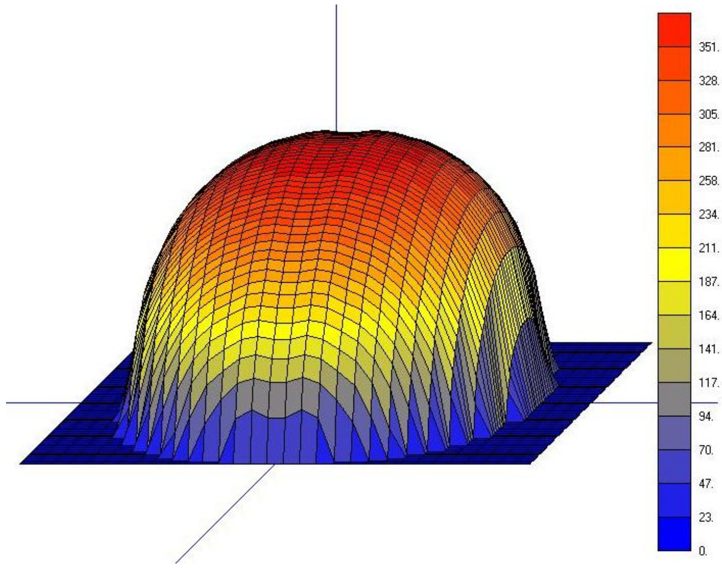

Figure 9. Inner Ring Contact Stress at 25% Co.

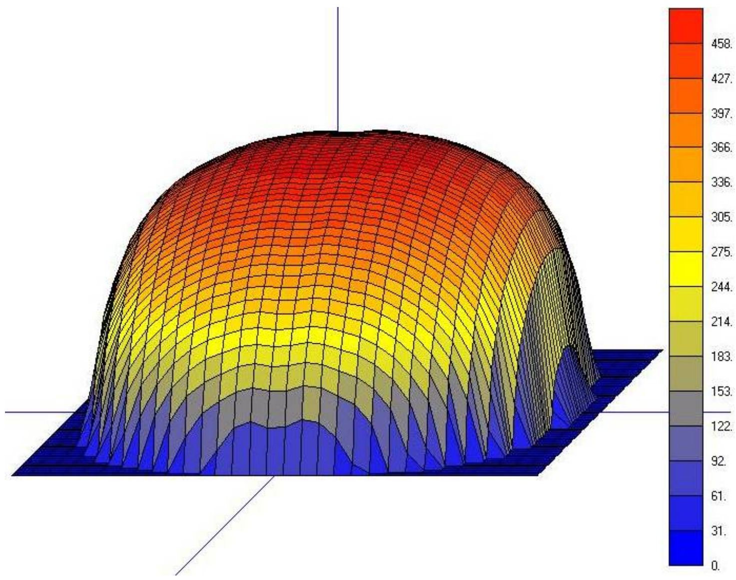

Figure 10. Inner Ring Contact Stress at 50% Co.

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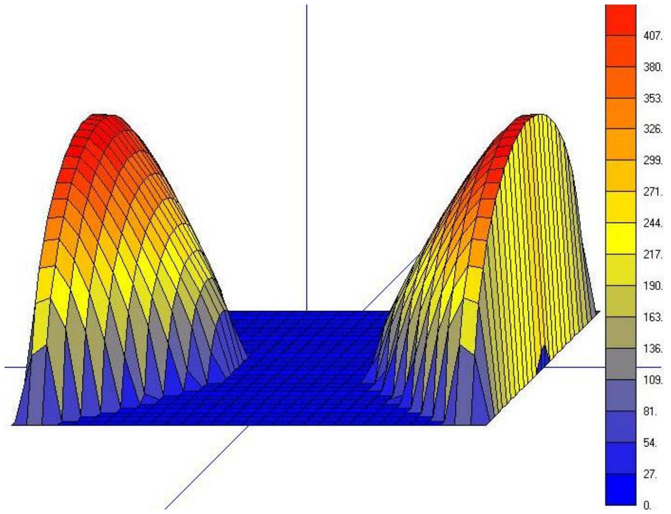

Figure 11. Outer Ring Contact Stress at 25% Co.

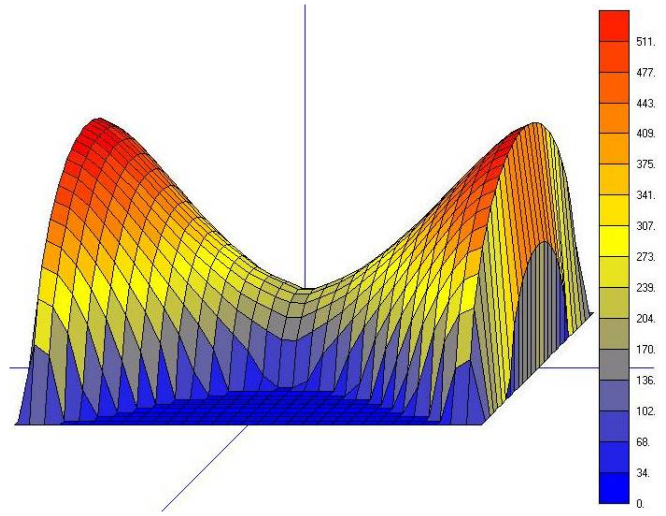

Figure 12. Outer Ring Contact Stress at 50% Co.

The three-point contact means that the roller is subjected to bending when it is under load. In order to accommodate this, the rollers in the Adapt bearing are manufactured from case-hardened steel.

2.6 Design Validation

Prototype bearings for design validation were manufactured to the ISO 2212 boundary dimensions. Heat-generation and bearing life tests were conducted. Multiple test stands were utilized with each stand fitted with two Adapt yoke bearings and two slave SRBs of the same size. Testing involved running the bearings through a matrix of load and speed combinations with speeds ranging from 1.200 RPM to 4.800 RPM and loads between 10% and 50% of the ISO calculated C1 rating. The test results showed that the design was sound. The bearings ran cooler than the comparator slave bearings and exceeded the calculated L10 life. These positive results allowed testing to progress to the next stage using production sized bearings.

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2.7 Testing and Field Trials

The Adapt bearing was presented to the Continuous Caster Division at Siemens VAI in Linz, Austria and they agreed to co-operate with Timken in arranging for field trials to be carried out at a commercial production caster. The agreed bearing sizes for these trials were full complement versions of the 4024 and 4032 bearings that would be installed on Siemens VAI caster roll assemblies.
The specific Timken part numbers are TA4024VC4 and TA4032VC4. The test bearings were manufactured at a production plant using standard production processes. Siemens VAI subsequently advised that voestalpine Stahl, also of Linz, Austria had agreed to trial the bearings on their new #6 caster. This caster was supplied by Siemens VAI and can produce slabs up to 235 millimeters thick and 1,650 millimeters wide at speeds up to 2.0 meters per minute. The 4024 bearings were installed in a straightener segment and the 4032 bearings in a horizontal segment. The smaller bearings were installed first with an initial successful performance milestone of 1 million tons cast. Life, heat generation and exaggerated misalignment tests of the same size bearings were conducted simultaneously at Timken.
The life and heat generation tests at Timken were done in a similar manner to the 2212 prototype bearings but with different speeds and a constant load equivalent to 40% of the ISO calculated C1 rating. The speeds ranged up to 1.600 RPM. In addition, forced misalignment testing was carried out at 0.2°, 0.35° and 0.55° of misalignment under loads ranging from 10 to 40 percent of the C1 rating.

3 TEST RESULTS

The in-house tests on these production bearings produced similar results to the testing of the prototype bearings. The Adapt ran cooler than the slave bearings and life exceeded the theoretical L10 value by a significant margin. The cooler operation suggests less sliding friction within the bearing and the improved life/load rating suggests improved reliability. The misalignment testing confirmed that the there was no roller or retainer assembly protrusion beyond the outer-ring faces up to the maximum specified misalignment of 0.5°.
The TA4024VC3 bearings installed at the voestalpine Stahl caster successfully reached 2,000,000 tonnes in January of 2012.
The TA4032VC3 bearings had successfully achieved 1,650,000 tonnes by this time.
The expectation is that the 4024 size bearings successfully reach 2.7 million tonnes and that the 4032 size reaches 4.0 million tonnes.

4 CONCLUSIONS

The objective of producing a reliable high capacity bearing offering simultaneous independent misalignment and axial float capabilities together with ease of installation, removal and inspection has been achieved. The successful trials at Timken and, more importantly, in a production caster have confirmed that the bearing meets the design intent and specification.

Acknowledgements

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