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# A Review on Friction Torque of Tapered Roller Bearings

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**Abstract— Modern machinery runs on high power density and speed to satisfy the needs of day-to-day services. Tapered Roller Bearings (TRBs) are often selected as it capable of accommodating high axial or radial load or combining axial and radial load simultaneously at high speed. On other hand it results in massive friction losses which causes energy loss and heat generation. An accurate estimation of friction torque measurements becomes essential to estimate bearing power loss accurately. This work presents an overview of analytical and experimental modeling and analysis methods for predicting friction torque with varying operating conditions in TRBs. A literature summary is presented along with future scope of work.**

***Keywords*—tapered roller bearing; friction torque; operating parameters, bearing temperature**

## I. INTRODUCTION

The history of the rolling bearings has more than 5000 years. Between A.D. 44 and 54, the Romans had created three different varieties of rolling bearings currently known as the ball bearings, cylindrical roller bearings and taper roller bearings (TRBs) [1]. TRBs are important components in various mechanical machineries as offering smooth rotational motion with combine high radial and axial load carrying capacities. The development of early TRBs marked a significant expansion in bearing technology. H. Timken [2] first invented TRB and became the most famous invention as its principal object was to reduce the friction in wagon wheels and transfer the load smoothly. As the heat generation rate increase the friction torque in TRBs hence previously it had not been employed for high-speed applications. However, developments in bearing design, accuracy in manufacturing field and identification of methods of heat removal via lubrication have moderately increased the acceptable operating speeds for TRBs [3]. In last few decades, many researchers have developed empirical equations for the prediction of friction torque accurately [4]. The friction torque produced in TRBs merely divided into two way a) load dependent friction torque that varies with the applied load and b) load independent one that regardless of the load [5].

Load dependent friction torque includes a) rolling friction involving rollers and raceways b) sliding friction occurring between the rollers ends and rib; while load independent friction torque includes a) sliding friction between rollers and cage; and (b) drag caused by the viscosity of the lubricant. A accurate estimation of the friction torque for any rolling bearing at moderate applied load and speed, load dependents and load independents components are necessary. At limited speed the effect of load independent components are relatively small as compared to the former

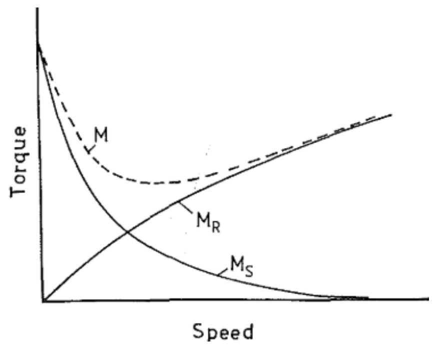


Fig.1 TRBs torque composition with load dependent components [6]

one and hence in majority research only load dependent components has been included for analysis [6][5]. Fig.1 shows the friction toque composition with dependent load and Fig.2 with dependent and independent load components.

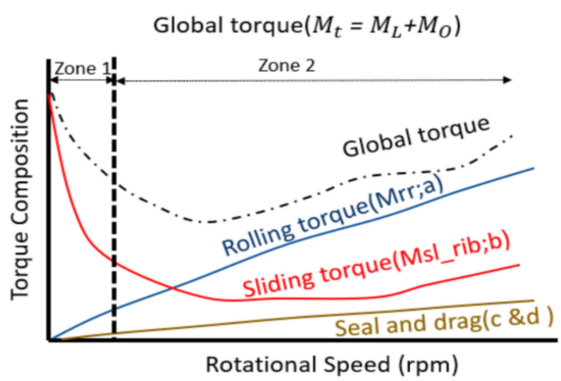


Fig.2 TRBs torque with load dependent and independent components [5]

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Wu et al. [7] presented a review about the examination of the theoretical models for analyzing friction torque in rolling bearings(RBs) with outline of various measurement techniques for assessing. A detailed analysis was provided for the measurement principles associated with different methods based on existing activities. Additionally, an evaluation of the current state of assessing the frictional characteristics of rolling bearings is presented. Wide discussion presented for friction torque in TRBs also. The discussion concludes with future prospects for the characterizing the friction torque properties of RBs.
Z. H. Wu et. al. [8] indicated that normally with compared to oil lubrications, grease in a RBs has many advantages as large operating temperature span, high excessive pressure and adhesion property and the establishment of the lubricating device become relatively simple. However, Lugt [9] indicate that the major disadvantage of the grease lubrication is it have limited life and as it work with the mechanical components the grease structure deteriorate with temperature rise and even oxidation takes place. Author conducted a detailed review on the rolling contact bearing that were grease lubricated as RBs commonly employ grease lubrication due to its wide verity applications. As the viscosity of grease is high it prevents leakage from the bearing, simplifies design of the system and provide effective sealing properties.

## II. RESEARCH ON MODELING AND ANALYSIS OF FRICTION TORQUE

Wren, I. F. [10] utilized EHL theory to examine the bearing contact and confirmed the presence of complete film lubrication. Additionally, their friction measurements indicate that the contribution of the rib roller end contact to the overall bearing torque is insignificant.
Witte [11] developed operating torque predicting method that established on dimensional analysis of the EHD variables associated with the operating conditions in TRBs for pure thrust and combined thrust and radial loads. Fig.**3** shows the section view of TRB with concentrated forces. As this method adopted some assumptions to develop the torque predicting equations, theoretical data shows underestimate torque than experimental data below 100-300 rpm. This limitation can be avoided above normal operating speed.

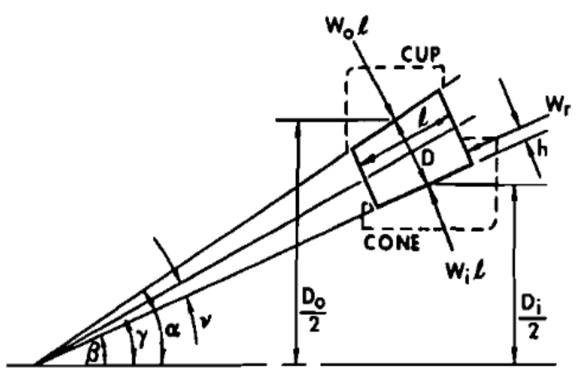


Fig.3 Cross section of the tapered roller bearing [11]

Karna [12] carried out experimental work to establish the analytical expression to predict the frictional torque on TRB with detached rib with axially applied load. Fig.**4** shows the dynamic equilibrium of the roller under internal and external forces Pi and Po to determine the proper expression of the rib torque. Fig.**5** shows that initially rib torque increase with the increase of the bearing load but gradually decrease rapidly with the speed increase and then remains insignificant.

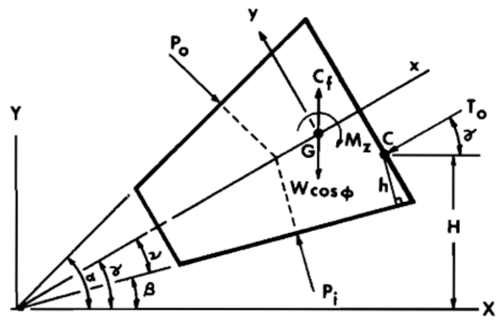


Fig.4 Internal and external forces of roller for dynamic equilibrium [12]

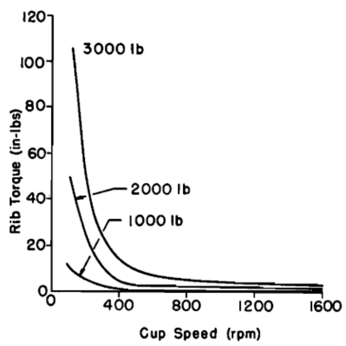


Fig.5 Schematic of experimental value of detached rib torque [12]

Jamison et.al. [13] presented skewing of rollers as shown in Fig.**6** in TRBs occurs due to several kinds of inconsistencies in manufacturing and the frictional force between the roller end and rib, resulting in a one-sided torque about the center of pressure in the roller pathway. These manufacturing inconsistencies generate arbitrary torques in both directions.

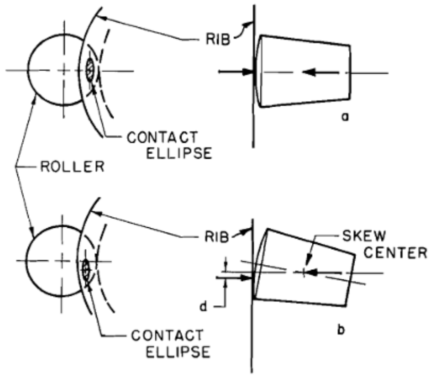


Fig.6 Roller skewed effect at the rib roller contact [13]

Glöckner [14] represented that the various friction elements in TRBs exhibit speed dependent performance under different lubrication conditions . Further in cases of boundary lubrication, where the lubricant film was insufficient for surface separation, sliding friction remains relatively constant. Conversely, in hydrodynamic lubrication, a load-bearing complete lubricant film was established in the bearings, even at extremely low speeds, leading to a significant reduction in sliding friction. The resulting curve displays a distinctive shape, featuring a prominent minimum point. In Fig.7 the continuous lines represent the amount of friction occurring at the guide flange, while the dashed lines depict the friction within the raceways.

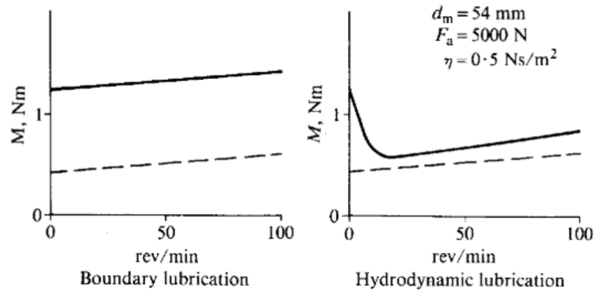


Fig.7 Friction torque in TRB with speed as functions [14]

Gadallah et al. [15] conducted Theoretical and experimental investigations to examine traction and film thickness under operating conditions that typically encountered in rib and roller end contacts as shown in Fig.**8** and validate the significance of geometry, kinematics and area as influential factors in lubrication within both the HD and EHD regimes.

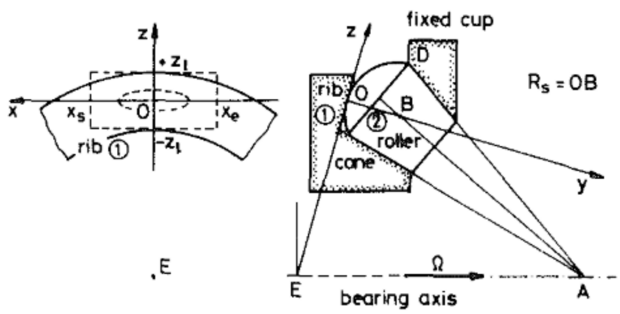


Fig.8 Rib Roller contact geometry [15]

Tsuneo Yamada [16] proposed that TRBs designed for operation in lower speed ranges exhibit typical characteristics, particularly in areas where sliding friction at the rib plays a significant role. These bearings are designed to optimize performance and moderate torque, with a focus on reducing frictional forces within the rib area as shown in Fig.9. Through particular bearing design and rigorous testing, various improvements had been achieved, leading to bearings that effectively minimize torque and increase overall operational efficiency.

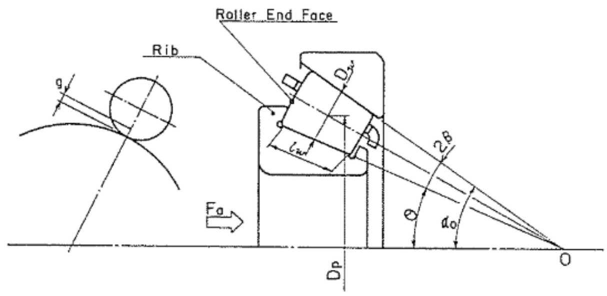


Fig.9 Torque calculation [16]

S. Aihara [5] introduced a novel torque calculation formula for TRBs subjected to axial loads address discrepancies observed in conventional formulas as the methods for estimating the running torque of TRBs at that time frequently demonstrated deviations from actual values, especially when axial loads were applied. Fig.10 show the concentrated load in TRBs for the torque calculations. S.

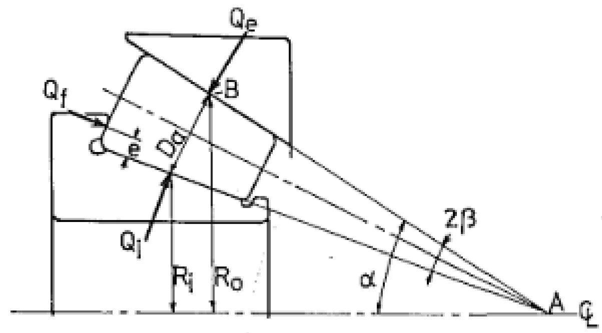


Fig.10 Concentrated forces on TRBs [6]

Witte and Hill [17] explained the measurement of the torque origins in a TRBs, with considerations on the torque characteristics of the interaction between the ribs and rollers. study provides insights and general observations concerning the operational conditions for each torque source. Fig.**11**shows the contact geometry used for the rearch in TRB.

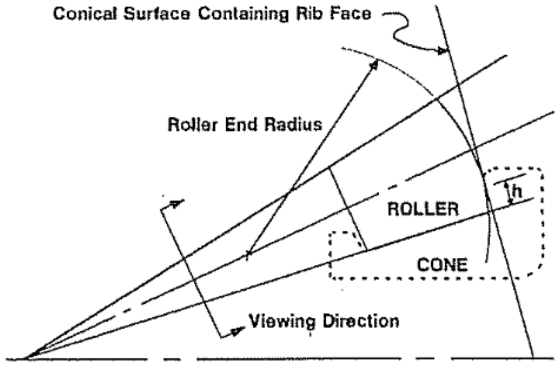


Fig.11 Contact geometry in TRB [17]

Zhou et. al. [18] proposed torque model using both theoretical analysis and experimental validation that involves EHL lubrication and able to predict torque for each roller. A bearing torque experiment test rig has been constructed to measure the torque of cone race, rib and cup race separately. The test data obtained from this rig has been used to verify the proposed torque model and found reasonable acceptance among bearing torques measured experimentally and the model predictions. Fig.12 shows the diagram of the different forces applied on the TRBs for the study.

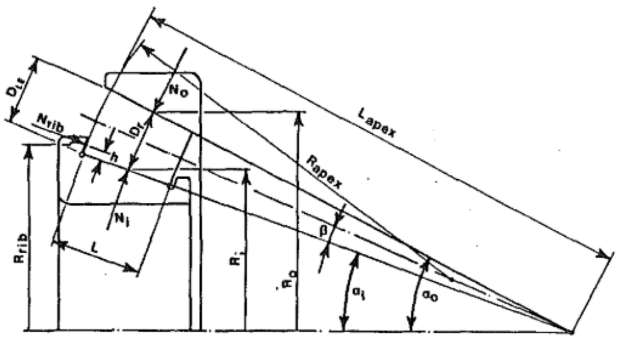


Fig.12 schematic of different forces acting on TRB [18]

Wang et al. [19] Investigates the frictional torque within a TRB and the corresponding heat generation rates at the contact points are influenced by the forces and internal speeds. In the case of a bearing is with fully or partially jammed rollers, the dynamic model was presented to determine cage angular velocities, bearing torques, and heat generation rates over time in findings of the mechanisms leading to bearing failure and for approximating the temperature distribution within a bearing assembly. Fig.**13** shows the bearing geometry diagram used for the study.

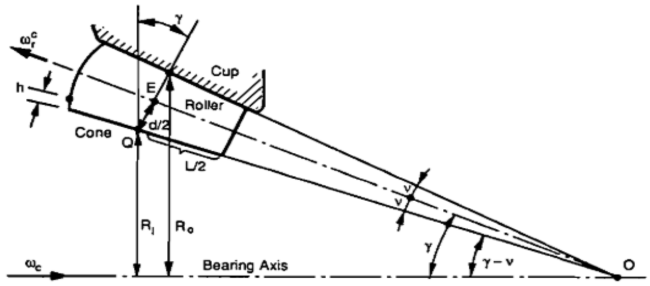


Fig.13 schematic of bearing geometry of TRB [19]

Matsuyama et. al. [20] conducted comprehensive analyses for EHD line contacts, covering a broad variety of dimensionless parameters as U, G, W and the inlet meniscus distance with aim to determine the viscous rolling resistance occurring among a roller and its raceway. As a output basic formulas for the viscous rolling resistance have been proposed. These resulting formulas were subsequently employed to calculate the frictional torque at the raceways. Fig.14 shows the used geometry.

H Matsuyama et al. [21] derived the simplified formula for viscous rolling resistance in TRBs for roller raceway contacts through comprehensive EHL lubrication analyses in line contacts. The frictional torque at both raceway contacts into the simplify formula in comparison with experimentally obtained frictional torque values.

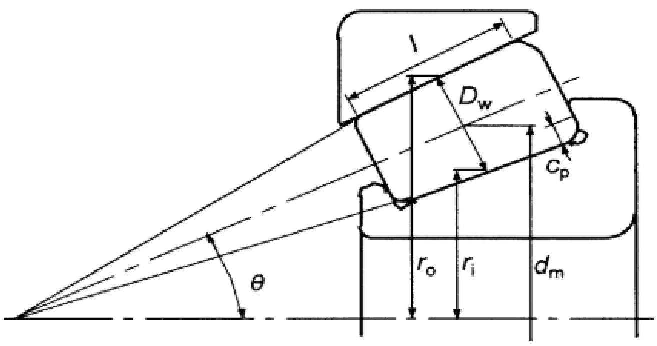


Fig.14 TRB Geometry considered for study[20]

Houpert [22] explained about bearing torque of Ball bearing (BB) and TRB calculations that the comparitions of these two bearings can be possible and can select the bearing acoording to the fuctions. Analytical models has been derived for the BB and TRB to compare and calculate the torque when the contact length for both the bearing are sililar.

Paleu et al. [23] created a test setup to observe the changes in both friction torque and temperature in highspeed rolling bearings, with the capability to run at speed till 120,000 rpm. An advanced data gaining methods and a virtual instrument were utilized to track the friction torque in bearing. The test findings indicate that hybrid rolling bearings exhibit lower friction torque and generated high temperature as compared to all steel bearings with the similar geometries.

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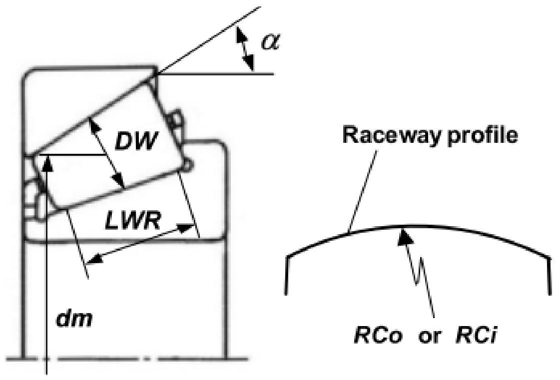


Fig. 15 Bearing different design factors [24]

H Matsuyama et al. [24] carried out a study to enhance the effectiveness of rear axle differentials by minimizing the friction torque in TRBs Fig. **15** that support the pinion. The study investigate the impact of the inner geometry and oil flow in the bearing on friction torque. A result shows that good amount of the in friction torque compared to a conventional bearing and its have significant benefits for vehicle fuel efficiency.

Bercea [25] conducted an experiment and measured friction torque on the outer ring of a TRB using a mineral oil (base oil) and mixtures of the base oil with low-density polyethylene additives. The results showed a significant decrease in friction when the polymer is added to the base oil. This reduction was credited to the creation of a protective film on the solid surface, created by the adsorption of large molecular coils present in the polymer.

Lugt [9] describes a review on grease lubrication that including grease flow, formation of fluid film and reduction with dynamic performance of the grease life. This study also reviewed the effect of the grease on friction torque with arious studies.

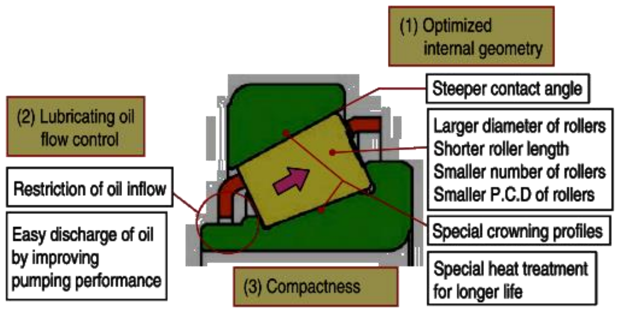


Fig. 16 Schematic of super low friction bearing [26]

Matsuyama [26] created a TRB with very low friction torque than standard ons and tested in drive pinion bearings of passenger car to validated the performance. This study could be usefull to improved vehicle fuel efficiency and reduced environmental impact on a global scale. Fig. **16** shows the schematic of the feature of the super low friction bearing.

Noguchi et al. [27] identfied a technique that minimized sliding friction in the TRBs using preciseness powder shot peening on the extensive surface of flange of the inner ring, resulting in a substantial reduction in bearing torque. The data verified that wear on the end face of the TRB remained consistent with previous levels and wear on the larger flange surface could be effectively prevented.

Ailin et al. [28] developed a basic model of TRB that simplifies the analysis by neglecting the interaction of multiple heat sources. The synthesis of the contact mechanics model, temperature model, and scuffing failure model has created in the computer programs. These programs enable the examination of the impact of bearing parameters with diverse materials and operational conditions on the thermal performance of bearings.

Hammami [29] demonstrated a work with aims to enhance the efficiency of drive axles, particularly focus on reduction of friction torque Fig.**17** in RBs The study investigates the tribological performance of five axle gear oils, each with distinct viscosity and formulations, to gain the impact on lubricant behavior in various types of rollings.

Xu et al. [30] bringout that the total friction torque is a combination of many factors includes elastic hysteresis loss, EHL roller friction torque, sliding friction at rib and roller end and lubricant drag friction of. Mainly the study was on three key parameters that axial predeformation, radial clearance, and angular misalignment.

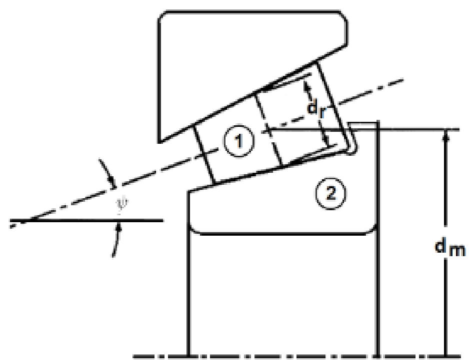


Fig.17 Schematic of simple TRB geometry [29]

These parameters were considered to analyze their influences of the friction torque of both rows of the DTRBs. The results of the investigation proposed that the friction torque in these two rows of DTRB is significantly affected by the mentioned parameters. [31] presented an analytical approach to compute the friction torque of a needle roller bearing (NRB) with considering with and without roundness error. The model has capasity to calculate rolling friction torques arising from elastic hysteresis, differential slipping friction torques, viscid friction torques induced by lubricating oil etc. However this concept can be applied to the TRB for the for the similar operating conditions.

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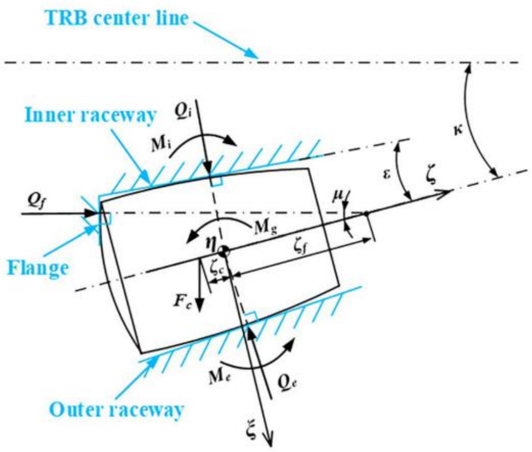


Fig. 18 A schematic of the load and moment at contact with the roller [32]

Liu et al. [32] investigated contacts at roller with raceways and flanges under defective conditions for defective TRBs to calculate the contact load and resultanting contact pressure distribution between every rollers and raceways. The results shows that defects in the raceway lead to major consequences and can induce an uneven and large contact pressure peaks may lead to increased friction torque in the defective TRBs. Fig. **18** shows the as the roller comes to the defected region the contact pressure chages immideatly. This study is important to understanding the effects of defects on the contact states and friction torque in TRBs is crucial for improving the design, reliability, and performance of such bearings.

Cruz et al. [33] presented a study related to the analysis of no-load power loss in a rear axle focusing on the torque loss in pre-loaded pinion TRBs with various parameters that influence this torque loss like starting torque, lubrication level and viscosity, and rotational speed. Result involves comparing experimental results with model estimations and eventually developing an empirical equation for the bearing friction torque based on the measurements of the starting torque in TRBs.

L. Liu et al. [34] presented a mathematical model about the friction torque in a PTRB based on operational principles and concered factors. Investigation shows fundamental PTRB properties, such as speed and loadand influence of the friction torque. The study involves the formulation and analysis of the impact of these properties on the friction torque. To validate the proposed friction torque variation principle, experiments are conducted using an actual PTRB.

Y. Wang et al. [35] investigated the impact of pits on the tribological characteristics and noise due to vibration indused by friction in TRBs subjected to lubrication starvation. The Pits were created on the outer ring of surface with the use of the laser marking equipment and a vertical type universal friction and wear machine was utilised to assess noise signals, vibration acceleration and friction force of the bearings. A comparative analysis was conducted involving the textured pit surface and a smooth surface concerning wear due to friction and vibration noise affecting. The findings indicate that the pit textured surfaces exhibit significantly lower friction force and wear loss compared to smooth surfaces.

Y. Wang et al. [36] explored about the dimpled textures affect the friction and the wear characteristics of TRBs in limited lubrication with various pattern of parameters such as dimple diameter, dimple depth, and area density. Dimples were created on the outer ring of TRBs with the use of a laser marking machine. The tribological properties of dimple textured TRBs under starved lubrication were examined using the vertical universal friction wear tester machine. By experimental investigations and results shows that when dimple textured average coefficients of friction (ACOF) and wear losses are significantly lower compared to non textured bearings.

Wrzochal et al. [37] introduced a novel industrial measurements to assess the friction torque of RBs during their manufacturing phase. The device enabling the evaluation of a diverse array of bearing dimensions with the application of extensive axial loads and the measurement of bearing mounting width.

Kelley et al. [38] applied as concept that initial used on microtextured angular contact ball bearings in conditions involving oscillating movement and that demonstrated a reduction in friction during reciprocating motion. With the same concept now the microtextures functioned as reservoirs for lubrication applied to sliding contacts in tapered roller bearings as TRB contact geometry shown in Fig. **19** with an exploration into whether the observed friction reductions are solely caused by the microtextures acting as lubricant reservoirs or if there is an additional beneficial HD effect caused by these microtextures. This micro structured bearing is then examined through a calculation based approach with different test rig measurements.

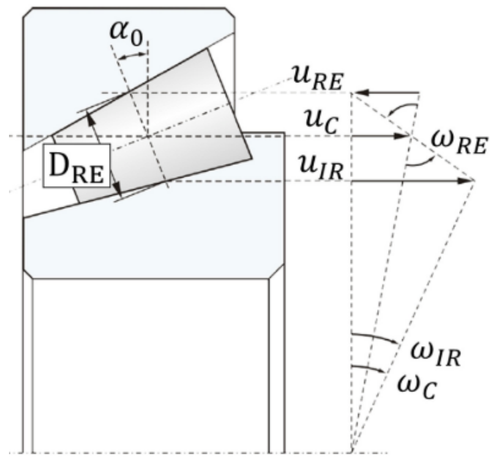


Fig. 19 Schematic of roller raceway contacts with forces[38]

Y. Liu et al. [39] established a quasi static model and the friction torque model for TRBs that take into account the geometric homogeneity of rollers as shown in Fig. **20.**

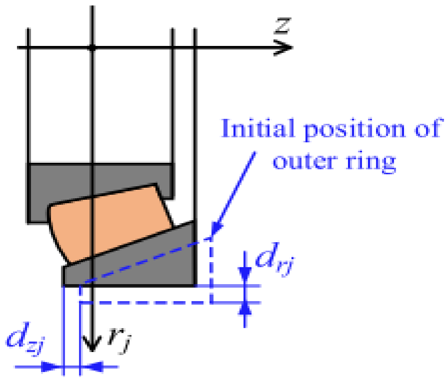


Fig. 20 Schamatic of initial position of the outer ring[39]

Y. Liu et al. [39] proposed models and analysis of how the geometric homogeneity of the tapered rollers influenced by the contact forces and friction properties in roller diameter deviation and the distributed pattern of all the rollers with respect to the diameter deviation. This investigation was carried out with varying axial loads, rotating speeds and cage slip rates.
P Wingertszahn et al. [40] presented a research that introduces a simulation model of parametric multibody to predict the friction torque with kinematics of TRBs. Here in this model the friction forces at the points of the contact concerning the inner ring rib and rolling element end face as well as at roller cage contacts have been considered for the accurate results. With numerious several tests results, the model simulation results demonstrated the strong agreement with measured friction torque different variables such as speed, thrust load, temperature and radial load.
Manjunath et al. [5] examined the torque due to rolling resistance and thermal inlet shear factor within TRBs through number of organized experiments employing a modular test setup. The research involves testing measurements of the overall frictional torque when subjected to axial load at varying speeds and oil temperatures. Guohua Cai et al. [41] presented an experimetal method to measure the heavy radial load in TRBs without modification in the TRBs. The test was conducted with maximum rotational speed 2000 rpm and applied radial load of 19.4 kN. LI XinBin et al. [42] identified a calculating method to findout friction torque based on the lubrication condition in TRBs under combined axial and radial load with validation of the experiemtal results. Seungpyo Lee et al. [43] identified technique to findout FT in TRBs under material uncertainities with roller geometries and obtained resuits depicted that this method of evaluting FT can be utiliesd in design of the TRBs. Gang Hu et al. [44] successfully developed and validated a theoretical and simulation model to measure the correlation among preload force and bearing FT in disc cutters and found good agreement with the experimental data.

## III. FRICTION TORQUE MODELS (FTMS) FOR TRBS SYSTEM

In last few dacads numerous work has been proposed to predict the the friction torque in TRBs. The early friction torque models were suggested by [11] and [12] for roller raceway and large rib roller end respectively. After word [16] considered rib roughness, [6] suggested FTM with different bore size while [17] had suggested FTM for rib roller end contact with preload consideration [18] suggested FTM based on lubrication contaminations affected at race way rolling, rib roller end contacts. Later on many researcher had work on different friction models with different criteris and methodologies. The detailed summury of the review of the friction torque for TRBs are illustrated Table.1.

Table 1 Summery of the review of the friction torque in TRBs in literature review

| Paper | Year | Area of Consideration for the study | Lubrication | N (RPM) | Bearing Temp | Axial Load LA (N) | Radial Load LR(N) | Programming Model | Experiment Set up | Numerical Model /Analysis |
|---|---|---|---|---|---|---|---|---|---|---|
| [11] | 1973 | Roller raceway | oil | 200 to 4000 | ✓ | 1000 | 2445-6890 | ✓ | | ✓ |
| [12] | 1974 | Large rib roller end | oil | 100-1500 | ✓ | 3000 | | | ✓ | ✓ |
| [13] | 1977 | skewing of rollers | oil | 15 in/s | | 100 pound | | | ✓ | |
| [14] | 1983 | selection of suitable lubricants | oil | 100 | | 0-8000 | | | ✓ | ✓ |
| [15] | 1984 | rib-roller end contact | oil | 500-1000 | | 10-320 | | | ✓ | ✓ |
| [16] | 1986 | Rib roughness 0.2-0.8 um | oil | 50 | ✓ | 3200 | | | ✓ | ✓ |

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| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| [6] | 1987 | Bore size (17 mm to 120 mm) | oil | 1000-3000 | ✓ | | | | ✓ | ✓ |
| [17] | 1987 | Rib- Roller End Contact | oil | 200-2660 | | Preload | Preload | | ✓ | ✓ |
| [18] | 1991 | Race way rolling , rib roller end contacts with contamination | oil | 5000-30000 | | | | | ✓ | ✓ |
| [19] | 1993 | Excessive Sliding Conditions | oil | 560 | | | 80000 | ✓ | ✓ | ✓ |
| [20] | 1998 | roller-raceway contact | oil | 200-1000 | | 1600-32000 | | | ✓ | ✓ |
| [21] | 2001 | roller-raceway contacts | oil | 100-1500 | | 2000-32000 | | | ✓ | ✓ |
| [22] | 2002 | Race Contact Length | oil | 0-10000 | | 13400 | | | ✓ | ✓ |
| [45] | 2003 | Bearing performance | oil | -- | -- | -- | -- | | ✓ | ✓ |
| [23] | 2004 | internal geometry, and oil flow | oil | 500-3000 | | 4000 | | | ✓ | ✓ |
| [46] | 2004 | under combined axial and radial loading | oil, Grease | 0-4000 | | 1500-5500 | 0-16500 | | ✓ | ✓ |
| [47] | 2008 | load, rotational speed, and viscosity of lubricant, along with the varied bearing torque with that different running condition. | Grease | 0-1400 | | 12000, 15000 | | | ✓ | ✓ |
| [48] | 2009 | Typical applications | oil, Grease | 500 | | 40000 | 53000 | | ✓ | ✓ |
| [49] | 2010 | performance of lubricants | Different Grease, And Different oil | 0 -6000 | | 7000 | | | ✓ | ✓ |
| [26] | 2010 | Reduced Contact area, crowning profiles, oil flow control | oil | 0-8000 | | No load | No Load | | ✓ | ✓ |
| [50] | 2014 | preloaded bearing subjected to combined radial load, axial load and tilting load | | | | 544 KN | 451 KN | | ✓ | ✓ |
| [51] | 2014 | bearing friction due to parallel axes | oil | 1000-5000 | | 1000 | 3000 | | ✓ | ✓ |
| [28] | 2014 | analysis of temperature filed and scuffing failure of TRBs | Grease | 5600 | 22-24 | 300 | | | ✓ | ✓ |
| [27] | 2014 | the large flange surface of the inner ring | oil | 500 | | 10000 | | | ✓ | ✓ |
| [52] | 2015 | bearing temperature at varying speeds, different grease filling ratios and large end radius of roller | Grease | 1543 - 3000 | | 25000 | 75000 | ✓ | | ✓ |
| [53] | 2015 | optimal operating conditions with Preload, radial load, axial load and friction torque | oil | | | -200 | 62500 | | ✓ | ✓ |
| [54] | 2015 | Performance Analysis Based on Romax | -- | | | 0-400 | | ✓ | | ✓ |
| [55] | 2015 | Geometric Error (roundness errors considered at inner and outer races) | | 1000 | | Preload 1500 | 500-1000 | ✓ | ✓ | ✓ |
| [56] | 2015 | Drag and Churning Losses | oil | 1000-6000 | | 0-1000 NM | | ✓ | ✓ | ✓ |
| [57] | 2016 | Deflection of Bearing | -- | 500 | | 400-1400 | | | ✓ | ✓ |
| [58] | 2016 | effect of angular misalignment | oil | 500-3000 | | 1000 | | ✓ | | ✓ |
| [59] | 2017 | effects of bearing load, radial clearance and angular misalignment | | 500 | | | 25-250 | ✓ | ✓ | ✓ |
| [60] | 2017 | bearing preload and no-load torque | oil | 2000-4500 | | Preload | | ✓ | ✓ | ✓ |

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|---|---|---|---|---|---|---|---|---|---|---|
| [29] | 2018 | five different axle gear oils with different viscosity and formula used as lubrication | oil | 9500 | | 4000-7000 | | | ✓ | ✓ |
| [61] | 2018 | effect of the radial load with combine effect of the inner raceway velocity and roundness error | oil | 500-3000 | | | 1000-4000 | | ✓ | ✓ |
| [62] | 2019 | effect of temperature on bearing preload | oil | 1000-5000 | | Preload | | | ✓ | ✓ |
| [30] | 2019 | angular misalignment considered with axial pre deformation and initial radial clearance | oil | 0-3500 | | 4000 | 5000 | ✓ | | ✓ |
| [63] | 2019 | Roller skewing | Dry lubricated | 60 | | Preload | Preload | | ✓ | ✓ |
| [64] | 2019 | different characteristics of vibration on a roller bearing with the waviness error | oil | 1800 | | 15000 | | ✓ | | ✓ |
| [32] | 2020 | Defect on Roller-Raceway | oil | 1500 | | 1500 | 2500 | | ✓ | ✓ |
| [65] | 2020 | waviness effect on the single part and all parts of the bearing | Gas –oil mixture | 500-2000 | | 20 | | | ✓ | ✓ |
| [33] | 2021 | effect on starting torque when considering the bearing mean diameter and width and the oil dynamic viscosity at varying operational speed | oil | 2000 - 2500 | | Preload | No Load | | ✓ | ✓ |
| [66] | 2021 | new optimized geometry of TRBs with misalignments | oil | 2000, 4000 | | 5000 | 1000 | ✓ | ✓ | ✓ |
| [67] | 2021 | New resin cage shape with reduced inner diameter on small side, open concave shape to inner diameter, optimized design of roller | oil | 2000, 5000 | | 3000 | | | ✓ | ✓ |
| [36] | 2022 | influence of dimple textures with parameters under starved lubrication | starved lubrication | | | 1500 | 1000 | | ✓ | ✓ |
| [35] | 2022 | Influence of Pits on the Tribological Properties and Friction-Induced Vibration Noise of Textured Tapered Roller Bearings | starved lubrication | | | 40000 | | | ✓ | ✓ |
| [39] | 2022 | Geometric Homogeneity | oil | 1000 | | 10000 | | ✓ | | ✓ |
| [68] | 2022 | raceways roughness and convexities at inner and outer ring | oil | 100,200 | | 500 - 10000 | | | ✓ | ✓ |
| [37] | 2022 | Rolling raceway | oil | 50,150, 250 | | 11000 | | ✓ | ✓ | ✓ |
| [69] | 2022 | Oil Bath TRBs with high speed | oil | 2418 | ✓ | 16000 | 53000 | ✓ | ✓ | |
| [38] | 2022 | microdimple-textured surfaces for RBs | Grease | 10 | | 40000 | | | ✓ | ✓ |
| [5] | 2023 | rolling resistance considering EHL at various operating conditions. | oil | 220 to 2200 rpm | | 2.5–45 kN | | | ✓ | ✓ |
| [41] | 2024 | Roller and raceway | Oil | 2000 | ✓ | | 19400 | | ✓ | |
| [42] | 2024 | Rib roller end contacts | Oil / Grease | 2500 | | 37 | 232 | ✓ | ✓ | ✓ |
| [43] | 2024 | Roller geometries and material uncertainties | Oil | | | ✓ | | ✓ | ✓ | ✓ |
| [44] | 2025 | Roller deformation | Oil | low | | 25000 Preload | | | ✓ | ✓ |

## IV. CONCLUSIONS

The presented article provided a comprehensive overview of the present situation of continuing research on the friction torque in TRBs. Friction torque usually considered to evaluate the performance or the conand the life of RBs as it directly related to the power loss and heat generation in bearing. The production of friction torque involves many influence factors such as operating conditions, loading and preloading conditions, lubrications, heat generation etc. For bearings, geometric error and defects on it is common problems came across in engineering applications and manufacturing processes. As a result, it concerns the rotational accuracy, noise and vibration intensities of whole systems and affect overall performance. Raceway convexities and surface roughness directly affects on the performance of roller and raceways and thus it is of great practical importance to know the influence it on friction torque of bearings. The review of various studies has revealed a comprehensive understanding of the factors influencing friction torque with ranging from geometric parameters and material properties to lubrication conditions. Researcher have employed diverse experimental investigations, methodologies, including analytical models and numerical simulations to explore the intricate interplay of these factors.

While considerable development has been made in unraveling the complexities of friction torque in TRBs, there remain gaps in knowledge and avenues for further exploration. As the field continues to evolve, it is crucial for researchers to collaborate and share insights to collectively advance in effects of the bearing geometrical parameters such as raceways convexity, excessive loading conditions, estimation of time varying friction moment during the bearing performance, effect of friction torque using grease with geometric conditions, Micro textured TRBs with bearing geometrical errors, effect of contaminated lubricants and vibration along with geometry error and effect of the temperature of bearing parts at different speeds, grease filled ratios along with geometric error on friction torque in TRBs. The variability in findings across different studies underscores the need for a standardized approach to experimental setups and measurement techniques.This literature review sets the stage for the present research, emphasizing the importance of addressing the existing knowledge gaps and contributing to enhance the field forward.

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