

BALL BEARING STIFFNESS. A NEW APPROACH OFFERING ANALYTICAL EXPRESSIONS

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ABSTRACT

Space mechanisms use preloaded ball bearings in order to withstand the severe vibrations during launch. The launch strength requires the calculation of the bearing stiffness, but this calculation is complex. Nowadays, there is no analytical expression that gives the stiffness of a bearing. Stiffness is computed using an iterative algorithm such as Newton-Raphson, to solve the nonlinear system of equations.

This paper aims at offering a simplified analytical approach, based on the assumption that the contact angle is constant. This approach gives analytical formulas of the stiffness of preloaded ball bearing.

Notations

a	Semimajor axis of contact ellipse
b	Seminor axis of contact ellipse
B	$= f_c + f_i - 1$ Total curvature of the bearing
D	Ball diameter
d_m	Bearing pitch diameter
E	Modulus of elasticity
e	Axial deflection due to preload
f	$f_c = r_c / D$ Dimensionless parameter
F(k)	Elliptic integral of the first kind
K_b	Ball stiffness
k_a	Axial stiffness of paired bearing
k_r	Radial stiffness of paired bearing
PH	Hertzian pressure
P	Bearing preload
Q	Ball normal load
r_i r_c	Raceway groove curvature radius
R_x R_y	Equivalent curvature radius
S(k)	Elliptic integral of the second kind
Z	Ball complement
α	Contact angle
δ_a	Axial deflection
δ_n	Normal approach along the line of contact
δ_r	Radial deflection
c	$= 0,5 [1 + (\delta_a/\delta_r) \tan \alpha]$
γ	$= D \cos \alpha / d_m$ Dimensionless parameter
Γ	Curvature difference
κ	$= a/b$ Elongation of elliptic contact area
ν	Poisson's ratio

$$\rho = R_y / R_x$$

1 INTRODUCTION

Preloaded angular contact ball bearings are used in several applications, submitted to severe vibrations: spindles of machine tools, gyroscopes, and space or military mechanisms. The preload suppresses the backlash, which highly improves the strength to launch vibrations, but also offers pointing accuracy. Mastering bearing stiffness allows to define the optimum preload level. A too low preload generates a high gapping under launch vibrations, which generates shocks that may damage balls and tracks. A too high preload generates a high friction torque and degrades the life duration.

Bearing stiffness calculation is usually done using an iterative algorithm such as Newton-Raphson, because the contact angle depends on the loading. There is no analytical solution giving the bearing stiffness.

The purpose of this paper is to provide with an analytical expression of ball bearing stiffness, for a preloaded paired bearing.

2 BALL STIFFNESS

The calculation of the ball stiffness is complex. It is based on Hertz theory [1]. Jones proposed in 1946 a simplified calculation [2] [7]. But it leads to an underestimated ball stiffness by 5 to 10%.

2.1 Hertz theory

Under a normal load, the contact area between the ball and the ring is elliptic. The pressure manifold is a paraboloid. The maximum contact pressure is located at the centre of the elliptic area. It is called the Hertzian pressure and is given by following expression

$$PH = \frac{3Q}{2\pi ab} \quad (01)$$

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Table of Contents Ball Bearing Stiffness A New Approach Offering Analytical

1. Understanding the eBook Ball Bearing Stiffness A New Approach Offering Analytical
 - The Rise of Digital Reading Ball Bearing Stiffness A New Approach Offering Analytical
 - Advantages of eBooks Over Traditional Books
2. Identifying Ball Bearing Stiffness A New Approach Offering Analytical
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Ball Bearing Stiffness A New Approach Offering Analytical
 - User-Friendly Interface
4. Exploring eBook Recommendations from Ball Bearing Stiffness A New Approach Offering Analytical

- Personalized Recommendations
- Ball Bearing Stiffness A New Approach Offering Analytical User Reviews and Ratings
- Ball Bearing Stiffness A New Approach Offering Analytical and Bestseller Lists
- 5. Accessing Ball Bearing Stiffness A New Approach Offering Analytical Free and Paid eBooks
 - Ball Bearing Stiffness A New Approach Offering Analytical Public Domain eBooks
 - Ball Bearing Stiffness A New Approach Offering Analytical eBook Subscription Services
 - Ball Bearing Stiffness A New Approach Offering Analytical Budget-Friendly Options
- 6. Navigating Ball Bearing Stiffness A New Approach Offering Analytical eBook Formats
 - ePub, PDF, MOBI, and More
 - Ball Bearing Stiffness A New Approach Offering Analytical Compatibility with Devices
 - Ball Bearing Stiffness A New Approach Offering Analytical Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Ball Bearing Stiffness A New Approach Offering Analytical
 - Highlighting and Note-Taking Ball Bearing Stiffness A New Approach Offering Analytical
 - Interactive Elements Ball Bearing Stiffness A New Approach Offering Analytical
- 8. Staying Engaged with Ball Bearing Stiffness A New Approach Offering Analytical
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Ball Bearing Stiffness A New Approach Offering Analytical
- 9. Balancing eBooks and Physical Books Ball Bearing Stiffness A New Approach Offering Analytical
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Ball Bearing Stiffness A New Approach Offering Analytical
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine Ball Bearing Stiffness A New Approach Offering Analytical
 - Setting Reading Goals Ball Bearing Stiffness A New Approach Offering Analytical
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Ball Bearing Stiffness A New Approach Offering Analytical

- Fact-Checking eBook Content of Ball Bearing Stiffness A New Approach Offering Analytical
- Distinguishing Credible Sources

13. Promoting Lifelong Learning

- Utilizing eBooks for Skill Development
- Exploring Educational eBooks

14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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