

# 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	$= \frac{1}{r_1} + \frac{1}{r_2} - 1$ Total curvature of the bearing
D	Ball diameter
$d_m$	Bearing pitch diameter
E	Modulus of elasticity
e	Axial deflection due to preload
f	$f = r_c / D$ Dimensionless parameter
$F(k)$	Elliptic integral of the first kind
$K_a$	Ball stiffness
$k_a$	Axial stiffness of paired bearing
$k_r$	Radial stiffness of paired bearing
$p_H$	Hertzian pressure
P	Bearing preload
Q	Ball normal load
$r_1, r_2$	Raceway groove curvature radius
$R_x, R_y$	Equivalent curvature radius
$S(k)$	Elliptic integral of the second kind
Z	Ball complement
$\alpha$	Contact angle
$\delta_a$	Axial deflection
$\delta_n$	Normal approach along the line of contact
$\delta_r$	Radial deflection
$\varepsilon$	$= 0.5 [1 + (\delta_a / \delta_r) \tan \alpha]$
$\gamma$	$= D \cos \alpha / d_m$ Dimensionless parameter
$\Gamma$	Curvature difference
$\kappa$	$= a / b$ Elongation of elliptic contact area
$\nu$	Poisson's ratio

$$p = \frac{R_y}{R_x}$$

## 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

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

# Ball Bearing Stiffness A New Approach Offering Analytical

**Hamed Kalhori**



## **Ball Bearing Stiffness A New Approach Offering Analytical:**

**Proceedings of the 7th International Conference on Industrial Engineering (ICIE 2021)** Andrey A.

Radionov,Vadim R. Gasiyarov,2022-01-01 This book highlights recent findings in industrial manufacturing and mechanical engineering and provides an overview of the state of the art in these fields mainly in Russia and Eastern Europe A broad range of topics and issues in modern engineering is discussed including the dynamics of machines and working processes friction wear and lubrication in machines surface transport and technological machines manufacturing engineering of industrial facilities materials engineering metallurgy control systems and their industrial applications industrial mechatronics automation and robotics The book gathers selected papers presented at the 7th International Conference on Industrial Engineering ICIE held in Sochi Russia in May 2021 The authors are experts in various fields of engineering and all papers have been carefully reviewed Given its scope the book will be of interest to a wide readership including mechanical and production engineers lecturers in engineering disciplines and engineering graduates Proceedings of the 4th International Conference on Industrial Engineering Andrey A. Radionov,Oleg A. Kravchenko,Victor I. Guzeev,Yuriy V.

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Engineering and Interdisciplinary Sciences This enables fast dissemination of the papers worldwide and increases the scope of visibility for the research contributions of the authors The Shock and Vibration Digest, 1992 **Applied Mechanics Reviews**, 1973 Nonlinear Dynamical Systems in Engineering Vasile Marinca, Nicolae Herisanu, 2012-01-05 This book presents and extends different known methods to solve different types of strong nonlinearities encountered by engineering systems A better knowledge of the classical methods presented in the first part leads to a better choice of the so-called base functions These are absolutely necessary to obtain the auxiliary functions involved in the optimal approaches which are presented in the second part Every chapter introduces a distinct approximate method applicable to nonlinear dynamical systems Each approximate analytical approach is accompanied by representative examples related to nonlinear dynamical systems from various fields of engineering **Inverse Dynamics Problems** Hamed Kalhori, 2021-06-15 The inverse dynamics problem was developed in order to provide researchers with the state of the art in inverse problems for dynamic and vibrational systems Contrasted with a forward problem which solves for the system output in a straightforward manner an inverse problem searches for the system input through a procedure contaminated with errors and uncertainties An inverse problem with a focus on structural dynamics determines the changes made to the system and estimates the inputs including forces and moments to the system utilizing measurements of structural vibration responses only With its complex mathematical structure and need for more reliable input estimations the inverse problem is still a fundamental subject of research among mathematicians and engineering scientists This book contains 11 articles that touch upon various aspects of inverse dynamic problems Japanese Science and Technology, 1983-1984 United States. National Aeronautics and Space Administration. Scientific and Technical Information Branch, 1985 **Vibration-based Condition Monitoring** Robert Bond Randall, 2021-07-06 Vibration based Condition Monitoring Stay up to date on the newest developments in machine condition monitoring with this brand new resource from an industry leader The newly revised Second Edition of Vibration based Condition Monitoring Industrial Automotive and Aerospace Applications delivers a thorough update to the most complete discussion of the field of machine condition monitoring The distinguished author offers readers new sections on diagnostics of variable speed machines including wind turbines as well as new material on the application of cepstrum analysis to the separation of forcing functions structural model properties and the simulation of machines and faults The book provides improved methods of order tracking based on phase demodulation of reference signals and new methods of determining instantaneous machine speed from the vibration response signal Readers will also benefit from an insightful discussion of new methods of calculating the Teager Kaiser Energy Operator TKEO using Hilbert transform methods in the frequency domain With a renewed emphasis on the newly realized possibility of making virtual instruments readers of Vibration based Condition Monitoring will benefit from the wide variety of new and updated topics like A comprehensive introduction to machine condition monitoring including maintenance strategies condition monitoring methods and an explanation of the

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**Production at the Leading Edge of Technology** Thomas Bauernhansl,Alexander Verl,Mathias Liewald,Hans-Christian Möhring,2023-11-17 The German Academic Association for Production Technology WGP annually invites researchers coming from its institutes and from industry to contribute peer reviewed papers in the field of production technology This congress proceedings provides recent research results and findings on leading edge manufacturing processes Main aim of this scientific congress is to push forward existing borders in production and to provide novel solutions of Production at the Leading Edge of Manufacturing Technology The subtitle Technology Based Sustainable Production for Circular Economy of this year s congress emphasizes challenges for global productions in the light of climate change and resource scarcity Different sessions were held on the topics Environmentally neutral production e g energy and material efficiency Resilient Value Creation Systems Biointelligence Digitization as an Enabler for Sustainable Production Production Technologies for a Circular Economy

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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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