

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	$= r_c + r_i - 1$ Total curvature of the bearing
D	Ball diameter
d_m	Bearing pitch diameter
E	Modulus of elasticity
e	Axial deflection due to preload
f	$r_c = r_c / D$ 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_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
ε	$= 0.5 [1 + (\delta_a/\delta_r) \tan \alpha]$
γ	$= D \cos \alpha / d_m$ Dimensionless parameter
Γ	Curvature difference
κ	$= a / b$ Elongation of elliptic contact area
ν	Poisson's ratio

$$P = R_y / R_x$$

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

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

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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

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Recent Advances in Material, Manufacturing, and Machine Learning Bjorn Schuller, Rajeev Gupta, Rakesh Mote, Abhishek Sharma, J.P. Giri, R.B. Chadge, 2024-06-17 The main aim of the 2nd international conference on recent advances in materials manufacturing and machine learning processes 2023 RAMMML 23 is to bring together all interested academic researchers scientists engineers and technocrats and provide a platform for continuous improvement of manufacturing machine learning design and materials engineering research RAMMML 2023 received an overwhelming response with more than 530 full paper submissions After due and careful scrutiny about 120 of them have been selected for presentation The papers submitted have been reviewed by experts from renowned institutions and subsequently the authors have revised the papers duly incorporating the suggestions of the reviewers This has led to significant improvement in the quality of the contributions Taylor Francis publications CRC Press have agreed to publish the selected proceedings of the conference in their book series of Advances in Mechanical 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 basic problem of condition monitoring. An

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Recent Advances in Mechanism Design for Robotics Shaoping Bai,Marco Ceccarelli,2015-05-05 This volume contains the Proceedings of the 3rd IFToMM Symposium on Mechanism Design for Robotics held in Aalborg Denmark 2 4 June 2015 The book contains papers on recent advances in the design of mechanisms and their robotic applications It treats the following topics mechanism design mechanics of robots parallel manipulators actuators and their control linkage and industrial manipulators innovative mechanisms robots and their applications among others The book can be used by researchers and engineers in the relevant areas of mechanisms machines and robotics

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Electric Vehicle Tribology Leonardo Israel Farfan Cabrera,Ali Erdemir,2024-05-24 Electric Vehicle Tribology provides practical comprehensive guidance on a new and increasingly important area of tribology Building skills from fundamentals to solution design this book demonstrates the unique tribological techniques essential to the efficient electrification of transport systems Led by Professors with a combined three decades in industry and academia and collecting insights from experts around the world this book begins with the essential knowledge regarding both Electric

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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

ASME Technical Papers ,2000 **Dynamics under Uncertainty** Dragan Pamucar ,Dragan Marinkovic,Samarjit Kar,2021-09-08 The dynamics of systems have proven to be very powerful tools in understanding the behavior of different natural phenomena throughout the last two centuries However the attributes of natural systems are observed to deviate from their classical states due to the effect of different types of uncertainties Actually randomness and impreciseness are the two major sources of uncertainties in natural systems Randomness is modeled by different stochastic processes and impreciseness could be modeled by fuzzy sets rough sets Dempster Shafer theory etc

IUTAM Symposium on Exploiting Nonlinear Dynamics for Engineering Systems Ivana Kovacic,Stefano Lenci,2019-07-24 This is the proceedings of the IUTAM Symposium on Exploiting Nonlinear Dynamics for Engineering Systems that was held in Novi Sad Serbia from July 15th to 19th 2018 The appearance of nonlinear phenomena used to be perceived as dangerous with a general tendency to avoid them or control them This perception has led to intensive research using various approaches and tailor made tools developed over decades However the Nonlinear Dynamics of today is experiencing a profound shift of paradigm since recent investigations rely on a different strategy which brings good effects of nonlinear phenomena to the forefront This strategy has a positive impact on different fields in science and engineering such as vibration isolation energy

harvesting micro nano electro mechanical systems etc Therefore the ENOLIDES Symposium was devoted to demonstrate the benefits and to unlock the potential of exploiting nonlinear dynamical behaviour in these but also in other emerging fields of science and engineering This proceedings is useful for researchers in the fields of nonlinear dynamics of mechanical systems and structures and in Mechanical and Civil Engineering *Vibration of Rotating Systems* K. W. Wang, Dan Segalman, 1993

Advances in Design, Simulation and Manufacturing IV Vitalii Ivanov, Justyna Trojanowska, Ivan Pavlenko, Jozef Zajac, Dragan Peraković, 2021-05-25 This book reports on topics at the interface between manufacturing and materials engineering with a special emphasis on product design and advanced manufacturing processes intelligent solutions for Industry 4.0 covers topics in ICT for engineering education describes the numerical simulation and experimental studies of milling honing burnishing grinding boring and turning as well as the development and implementation of advanced materials Based on the 4th International Conference on Design Simulation Manufacturing The Innovation Exchange DSMIE 2021 held on June 8-11 2021 in Lviv Ukraine this first volume of a 2 volume set provides academics and professionals with extensive information on trends technologies challenges and practice oriented experience in the above mentioned areas

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