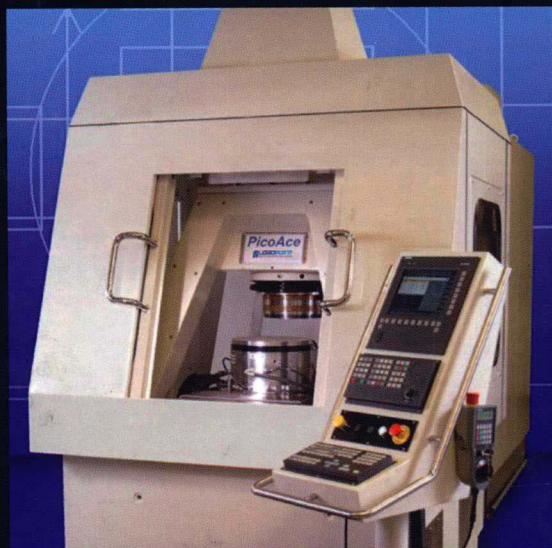


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Ultra-precision Bearings

Frank Wardle



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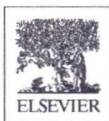
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Preface

The material presented in this book is based on the author's past experience, initially in the ball bearing industry and later in the air bearing and machine tool industries. In developing high- and ultra-precision bearings and machinery it became clear there was very little in the way of guidance for machine designers needing to achieve extreme precision or low motion errors. Yet over the last four or five decades this has become an increasingly important aspect of performance relevant to a growing number of new bearing applications in the computer, electronics and optical industries.

Traditionally, books on bearings have tended to emphasise the load carrying capacity and/or life aspect of performance where the failure criteria are generally related to wear, fatigue or seizure mechanisms. In ultra precision machinery, running accuracy, stiffness, damping and heat generation are more relevant bearing performance parameters, and bearing life may be limited by deterioration in any of these. As a result, this book primarily aims to provide a basic understanding of the mechanisms upon which these parameters depend for a range of ultra precision bearing types. The mechanisms identify most, if not all, of the influencing variables and at worst, enable the machine designer to make an informed judgement about a particular design scenario. But in many cases the mechanisms are used to develop reasonably accurate analytical formulae that enable the bearing or machine performance to be determined and optimised at the design stage.

In real machinery the freedom to select or design bearings is usually restricted by practical constraints such as, for example, space, aspect ratio, ease of assembly and access. In addition, the bearing design process is often a compromise requiring a trade off between dissimilar parameters such as stiffness and heat generation. Thus, in many applications, the challenge is to find the most suitable bearing rather than a mathematically optimised design. For this reason the preferred approach, adopted in this book, is to provide the designer with a calculation that they can use for their situation rather than standardised design charts.

A running accuracy of $0.1\mu\text{m}$ peak-peak is used as a criterion to distinguish ultra precision bearings from other types. Effectively this limits the book to the rolling bearings – single-row radial and angular contact ball bearings; hydrostatic and aerostatic externally pressurised fluid film bearings; hydrodynamic and aerodynamic herringbone and spiral groove fluid film bearings. For the fluid film bearings, the analysis is focused on the simple geometries, circular or annular pad and cylindrical journal that are most easily manufactured to high precision and are hence most widely used. But the basic principles apply equally to conical and spherical bearing forms.

Encouragement to write the book has come from colleagues in the precision machining industry, friends and family, particular thanks go to Professor Eric Marsh of Penn State University for many helpful comments and suggestions. Acknowledgements also go to my son David, who has programmed many of the bearing calculations and my daughter Amanda who has helped with illustrations and diagrams. Last but not least is my wife Vivien, without whose patience and understanding, the book would not have been completed.

About the author

Frank has 40 years experience in an industrial research environment, gained in the ball bearing, air bearing and precision machine tool industries.

Twenty years was spent as a research manager in the ball bearing industry, focusing on the development of special purpose bearing products, such as silent running bearings for military applications, high speed bearings for aircraft engines and high precision bearings for machine tools. Reduction in bearing noise and motion errors resulted from wide ranging improvements to manufacturing processes and control over application conditions, where he gained first-hand experience of manufacturing machinery and test equipment alike. He was given a best paper award by the I. Mech. E in 1988, for his work on quiet running bearings and another best paper award by the I. Mech. E's Tribology Group in 1989, for pioneering the use of ceramic balls in machine tool bearings.

Twelve years was spent as Technical Director with Loadpoint Ltd, developing air bearing products, manufacturing processes and precision machinery. Air bearing developments covered both aerostatic and aerodynamic bearing types. The former was related to diamond turning, grinding and disc verification applications, where low motion error was an important requirement, whilst the latter was aimed at optical scanning applications. He developed a novel electrochemical micro-machining process to machine the helical and spiral grooves in aerodynamic bearings and in the mid-1990s this was used to support hydrodynamic bearing developments in the computer hard disc drive industry. The process is now widely used by the hard disc drive and medical industries for fluid film bearing manufacture. Machine tool developments included a diamond turning lathe and a silicon wafer grinding machine.

Frank started Ultraprecision Motion Ltd in 2006, continuing industrial research and development in machine tool systems. Developments to date include Ultramill, an ultra precision five-axis micro-milling machine, micro-recessed air bearings for improving the stiffness and accuracy of ultra precision machine tool slideways and rotary tables, and Tempconet, an intelligent and adaptable machine tool control system.

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