A Novel Approach in the Application of Flexure Bearings in Primary Torque Standard Machines

A.C.P. Bitencourt[1], R. Theska[2], A. Wagner[2], H.A. Lepikson[3], L.A.G. Junior[3], W. L. Weingaertner[4]
[1]*Instituto Federal de Educação, Ciência e Tecnologia da Bahia, Brazil*
[2]*Technische Universität Ilmenau, Germany*
[3]*Universidade Federal da Bahia, Brazil*
[4]*Universidade Federal de Santa Catarina, Brazil*
antonio.carlos@ifba.edu.br

Abstract

An important characteristic of the bearing application in ultraprecise torque realization is small and predictable friction. However, other equally important requirements are the stable definition of the rotary axis and high repeatability. These requirements cannot be derived without a significant improvement in the typical characteristics of customary bearings. Flexure bearings provide favorable characteristics for torque realization. This work presents different variants of flexure bearings. It is shown how to predict flexure bearing behavior in order to enable the compensation of systematic fault effects. This therefore opens the way for the bearing requirements of ultraprecise torque realization.

1 Introduction

Torque Standard Machines (TSM) are the primary standard devices used to realize pure torque. The dead weight principle gives the best available metrological characteristics. Preceding works show that further improvements in small torque realization (Torque Range 1mNm-1Nm, $U_r = 1\times10^{-5}$, k=2) are particularly sensitive to the lever bearing characteristics [1]. The bearing defines the rotary axis and dominates the lever length definition. Different solutions for high precision bearings (knife edge bearings, air bearings and flexure bearings) have been analyzed in preceding works [2]. Flexure bearings provide the best characteristics for TSM application.

2 Flexure bearings

A flexure bearing is an elastic element that provides the relative rotation between two adjacent rigid members through flexing (bending). In terms of this rotary function, it can be considered as the structural correspondent of a bearing with limited rotation capability. Flexure bearings are widely used in precision engineering. They show almost no friction, but only internal bounding forces [3]. Flexure bearings have replaced knife-edge in precision weighing with mass comparison due to their superior repeatability. However, in TSM its application is relative new. It began with the development of strain-controlled cross-hinges as lever bearing and strain-controlled mass-hinges to connect the masses on each lever end, but its application is not as well developed as it is in weighing metrology, therefore there is an obvious opportunity to increase the metrological performance in TSM in particular for small torque realization [2].

A main drawback of flexure bearings is given by the strongly limited angle of rotation. Furthermore, flexure bearings do not provide a pure rotation around a fixed rotary axis because of the complex elastic behavior [4]. These effects can be reduced in the application of TSM if an appropriate horizontal lever control system is available. Nonetheless, there is a residual but highly repeatable deformation of the flexure bearing. With a detailed knowledge of the overall behavior of the bearing failure compensation can be applied. There are two approaches to design a flexure bearing: flexure hinges and leaf springs.

2.1 Flexure hinges

Flexure hinges are commonly made of rectangular blanks by removing two symmetric cut-outs. There are a variety of different cut out profiles. The most common curves, due to the manufacturing process, are symmetric conic-section: circle, ellipse, parabola and hyperbola. A few samples are shown in Figure 1.

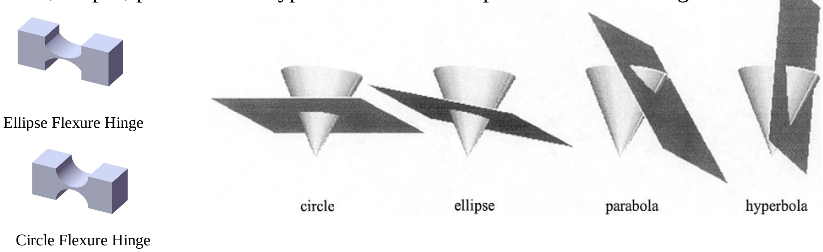
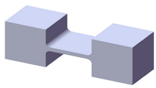


Figure 1: Common conic-section used in symmetric flexure hinge [5]

2.2 Leaf springs

Leaf springs act as bending beams over the whole length. There are two variants: corner-filleted flexure (monolithic) and cross leaf spring (mounted). The first one is more frequently used because of its high repeatability where there are no assembly error influences or relative movement between the parts.



Corner-filleted flexure hinge [6]

Asymmetric cross-spring bearing

Figure 2: Corner-filleted flexure and leaf spring bearing

Early works have shown different approaches (mathematical analytic modeling, finite element modeling and experimental ones) to compare these flexure variants [6]. They found that the corner-filleted hinge and leaf spring show lower stiffness than the elliptical or circular ones; however, they have lower stability of rotary center. One way to overcome this drawback is to adopt the asymmetric cross-spring layout [5-7]. In conclusion, corner-filled hinges in cross-spring layout respond to the design requirements to TSM application in the best way. A mathematical model is proposed to optimize flexure bearings with respect to stiffness and the shift of the rotary center.

3 Mathematical model for cross-spring flexure bearings

There are some mathematical models for flexure bearing in the literature. Most models are simplifications based on the bending or bulking behavior of the spring leaves. There are two mathematical approaches to predict flexure behavior: parametric and analytical. The parametric approaches aim to supply guidelines for the bearing design. The analytical approaches support more precise behavior models of flexure bearings. However, they require high computational effort and produce complex results which can not be applied directly. Other models describe the movement of the rotary axis with the use of a cinematic model. However, these cinematic models provide insufficient results to predict the bearing behavior. The present work adopts an intermediary solution, taking the advantages of both the parametric and analytical approaches. The mathematical model is presented in Bitencourt[7]. The developed mathematical model has been compared to finite element models and to others available in the literature. The parametric approach provides optimal results for the geometric parameters of flexure bearings. The analytical model, in turn, provides accurate measurements of the systematic behavior of flexure bearings. Calculations made with the use of the model [7] show that the best configuration for the flexure bearing is a non-symmetric cross spring bearing with an asymmetry factor of 12% and an angle of 30 degrees between the springs leaves [7], see Figure 2. The mathematical model and its related results will be presented in the poster.

4 Conclusion

Flexure bearings have the advantage of possessing highly predictable characteristics thus enabling compensation of inherent systematic errors. They are widely used in precision engineering devices. Different types of flexure hinges were evaluated. The confrontation with the design requirements of TSM application shows that the corner-filled hinge in cross-spring layout is the optimal solution. A mathematical model was developed to provide a solution in which the best configuration for the flexure bearing is a non-symmetric cross spring bearing with an asymmetry factor of 12% and an angle of 30 degrees between the spring leaves. In the future experimental tests will be carried out to adjust and enhance the mathematical model.

References:

[1] Bitencourt, A.C.P. *et. al.*. Solution Principles for Small Torque Standard Machine. In: Proceedings of the 53rd IWK, TU-Ilmenau, Ilmenau/Germany 2008

[2] Bitencourt, A.C.P. *et. al.*. Alternative concepts for high precision bearings in torque standard machines. Proc. of the Euspen International Conference, 2010

[3] Tian, Y.; *et. al.*. Closed-form compliance equations of filleted V-shaped flexure hinges for compliant mechanism design; Precision Engineering, 2010

[4] Lobontiu N. Compliant mechanisms: Design of flexure hinges. Boca Raton: CRC Press; 2002

[5] Lobontiu, N.; *et. al.*. Design of symmetric conic-section flexure hinges based on closed-form compliance equations; Mechanism and Machine Theory, 2002

[6] Xu, W. & King, T. Flexure hinges for piezo actuator displacement amplifiers: flexibility, accuracy, and stress considerations; Precision Engineering, 1996, 19, 4-10

[7] Junior. L.A.G. *et. al.*. Desenvolvimento de sistemas técnicos de precisão, de metrologia e de automação para padrão primário de baixo torque. XI SEMPPG, UFBA, Salvador/Brasil, 2010