

The Modal Analysis of Special Purpose Flexure Spring for Ground Applications

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Abstract

This research paper presents a comprehensive modal analysis of a special purpose flexure spring designed for ground applications. The study employed ANSYS Workbench software to investigate the natural frequencies of the flexure spring under different geometries and materials. Additionally, experimental measurements of the natural frequencies were conducted using an FFT analyzer to validate the numerical results. The results show that the proposed design significantly reduces electromagnetic interference and improves the performance of flexure bearings, thereby enhancing the accuracy and reliability of precision instruments. The findings of this research have implications for a wide range of applications in the aerospace, defence, precision instrumentation, medical devices, optical systems and scientific industries.

Keywords: — Flexure spring, Modal analysis, Electromagnetic effect, FFT analysis.

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1. Introduction

Flexure bearings are widely used in precision instruments due to their high stiffness, low friction, and minimal wear. These bearings operate by deflecting a thin metal strip, or flexure, to provide support and guidance for a moving element. However, electromagnetic fields generated by nearby electrical components can induce currents in the flexure, leading to unwanted motion and instability. This phenomenon is known as the electromagnetic effect and can significantly impact the performance of flexure bearings in critical applications.

The aim of this research paper is to investigate the electromagnetic effect on special-purpose flexure bearings designed for ground applications and propose a novel design to mitigate these effects. The study will focus on flexure bearings used in precision instruments, such as accelerometers, gyroscopes, and inertial measurement units, which require high accuracy and stability.

The paper begins with a brief overview of flexure bearings and their applications in precision instruments. It will then discuss the electromagnetic effect and its impact on the performance of flexure bearings. The research methodology will be presented, which includes both analytical and experimental methods. The paper will conclude with a discussion of the results and their implications for the design and operation of flexure bearings in-ground applications. The findings of this research will have significant implications for the aerospace, defense, and scientific industries, where the accuracy and reliability of precision instruments are critical.

Electromagnetic motors and flexure springs are two separate components, but they can be used together in some applications such as in precision positioning systems.

When an electromagnetic motor is used in conjunction with a flexure spring, the motor can influence the performance of the spring. The motor generates electromagnetic forces that can induce vibrations and noise in the system, which can in turn affect the performance of the flexure spring.

Additionally, the motor's magnetic field can interact with the flexure spring, leading to changes in the spring's stiffness and damping properties. This can cause the spring to behave differently than expected, which can impact the overall performance of the system.

However, by properly designing the system and accounting for these interactions, it is possible to mitigate these effects and achieve good performance.

1.1 Significance of Flexure Spring

Flexure bearings, also known as flexure springs, are significant due to the unique mechanical properties that make them ideal for precision applications. These bearings consist of a thin strip of material that deflects under load to provide support and guidance for a moving element. They offer several advantages over traditional bearings, including:

1. High stiffness: Flexure bearings have a high stiffness-to-mass ratio, meaning they can provide high levels of support with minimal material.
2. Low friction: Flexure bearings have low friction coefficients, resulting in minimal wear and improved reliability.
3. Precision motion: Flexure bearings provide precise motion control due to their low hysteresis and high repeatability.
4. Compact size: Flexure bearings can be designed to be very compact, making them ideal for applications where space is limited.
5. Minimal maintenance: Flexure bearings do not require lubrication, resulting in minimal maintenance requirements.

These advantages make flexure bearings suitable for a wide range of applications, including aerospace, defence, scientific instruments, and medical devices. Their high precision, reliability, and compact size make them particularly useful in applications where accuracy and performance are critical.

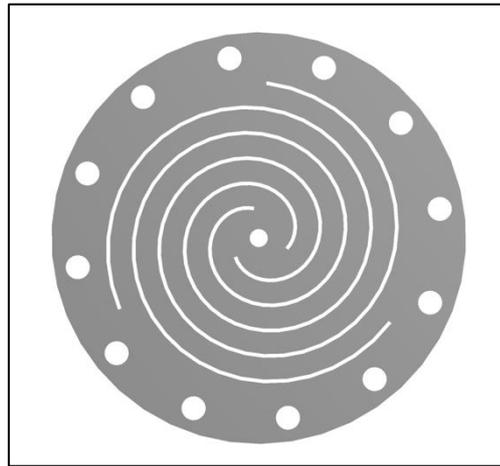


Fig. 1: Flexure Bearing

1.2 Applications

Flexure bearings are used in a variety of ground applications where precision, stability, and reliability are critical. Some common ground applications of flexure bearings include:

1. Precision measuring instruments: Flexure bearings are used in a variety of precision measuring instruments, including accelerometers, gyroscopes, and inertial measurement units. These instruments require high accuracy and stability to provide reliable measurements, and flexure bearings can provide the necessary support and guidance.
2. Optical systems: Flexure bearings, such as telescopes and cameras, are used in optical systems to provide precise motion control and stability. The low hysteresis and high repeatability of flexure bearings make them ideal for these applications.
3. Microscopes: Flexure bearings are used in high-resolution microscopes to provide precise motion control and stability, allowing for accurate imaging and analysis.
4. Semiconductor manufacturing: Flexure bearings are used in semiconductor manufacturing equipment to provide precise positioning of wafers and other components.
5. Aerospace and defence: Flexure bearings are used in aerospace and defence applications, including satellite attitude control systems and missile guidance systems. These applications require high precision and reliability, which can be provided by flexure bearings.

Overall, flexure bearings are used in a wide range of ground applications where precision, stability, and reliability are critical. Their unique mechanical properties make them ideal for these applications, providing precise motion control and stable support for moving elements.

Modal Analysis

Modal analysis is a technique used in mechanical analysis to determine the natural frequencies and mode shapes of a structure. It involves calculating the eigenvalues and eigenvectors of the structure's stiffness and mass matrices to determine its natural modes of vibration.

In modal analysis, the structure is modeled as a system of masses and springs, with the masses representing the components of the structure and the springs representing the stiffness of the connections between them. The natural frequencies and mode shapes of the structure are determined by solving the eigenvalue problem for the system, which involves finding the values of λ for which the determinant of the system matrix is zero.

The mode shapes of the structure describe the way in which it vibrates at each of its natural frequencies. Each mode shape is characterized by a pattern of displacement throughout the structure, with different areas of the structure vibrating in different directions and with different amplitudes.

Modal analysis is a useful tool for understanding the dynamic behaviour of mechanical structures and for identifying potential problems with their design or operation. It can be used to optimize the design of structures for specific operating conditions and to determine the effects of changes in the structure's configuration or operating conditions on its natural frequencies and mode shapes. Modal analysis is commonly used in a variety of industries, including aerospace, automotive, and civil engineering.

2. Methodology

The present analysis was carried out in ANSYS software. The modal analysis of flexure bearing is to estimate different modes of natural frequency. This process uses a simple hammer test using FFT for getting a fixed response.

Modal analysis of flexure bearings is an important tool for understanding their dynamic behavior and for optimizing their design for specific ground applications. The natural frequencies and mode shapes of a flexure bearing can be used to predict its response to external loads and to identify potential problems with its design or operation.

In a modal analysis of flexure bearings, the bearing is modelled as a system of masses and springs, with the masses representing the components of the bearing and the springs representing the stiffness of the flexure elements. The natural frequencies and mode shapes of the bearing are determined by solving the eigenvalue problem for the system, which involves finding the values of λ for which the determinant of the system matrix is zero.

The mode shapes of the flexure bearing describe the way in which it vibrates at each of its natural frequencies. Each mode shape is characterized by a pattern of displacement throughout the bearing, with different areas of the bearing flexing in different directions and with different amplitudes. The natural frequencies and mode shapes of the flexure bearing can be used to predict its response to external loads and to identify potential resonances or other issues that may affect its performance.

Boundary Conditions

To provide useful constraints, fixed supports were placed on the nodes located on the outer periphery, which represent the junctions between two components. As shown in Figure 2, all parts of the test setup had fixed support except for the flexure bearing, coil former, and shaft [8]. The boundary conditions were imposed for a flexure spiral angle of 560° , and the movements of the flexure in the axial direction were constrained by the inner nodes of the flexure. The periphery of the flexure spring had 12 holes that were fixed for all degrees of freedom, and a force was applied at the center of the flexure spring.



Fig. 2: Fatigue Life Setup

Part list of FL Setup

Sr. No.	Particulars	Material
1	Leg	SS304
2	Dead weight	SS304
3	Base plate	SS304
4	Mounting plate	SS304
5	Flexure mounting plate	SS304
6	Pole piece	Soft iron
7	Casing	SS304
8	Shafts	SS304
9	Spacer	Aluminum

Table 1: Part list of FL setup

ANALYSIS OF SETUP WITH MAGNET

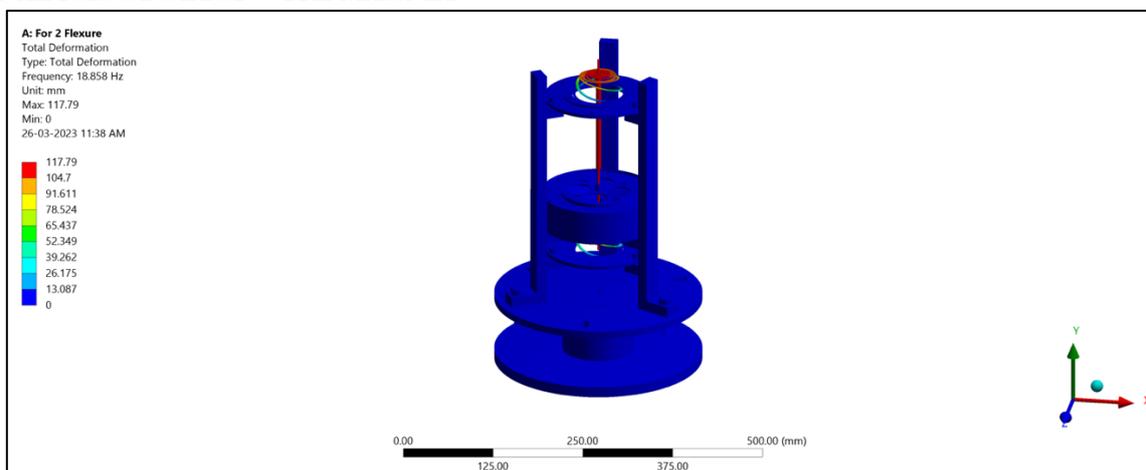


Fig. 3: Modal analysis of FL setup with magnet for 2 flexures

ANALYSIS OF SETUP WITHOUT MAGNET

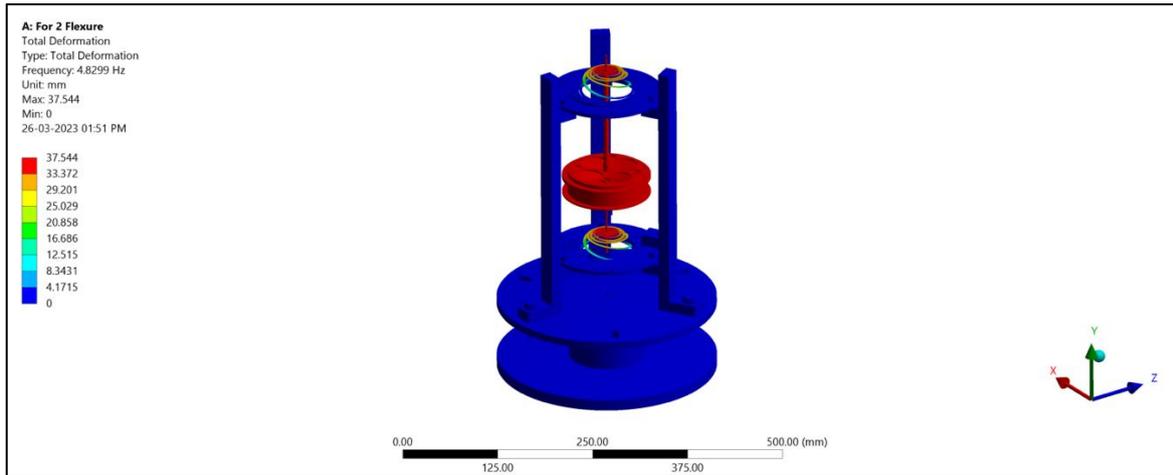


Fig. 4: Modal analysis of FL setup without magnet for 2 flexures

FFT Analysis

FFT analysis or Fast Fourier Transform analysis is a technique used in signal processing to transform a time-domain signal into its frequency-domain representation. It is a powerful tool for analyzing the spectral content of signals and is used in a wide range of applications, including audio processing, image processing, and vibration analysis.

The FFT algorithm is a computationally efficient method for calculating the Discrete Fourier Transform (DFT) of a signal. The DFT is a mathematical operation that converts a time-domain signal into its frequency-domain representation, by decomposing it into a sum of sinusoidal components with different frequencies and amplitudes. In FFT analysis, a signal is first sampled at regular intervals and converted into a discrete-time signal. The FFT algorithm is then applied to this discrete-time signal to compute its frequency-domain representation. The resulting spectrum shows the magnitude and phase of each of the sinusoidal components that make up the signal, as well as their frequencies.

FFT analysis is commonly used in vibration analysis to analyze the frequency content of mechanical vibrations. By applying FFT analysis to vibration signals from machinery, it is possible to identify the frequencies of the different components of the machine and to detect any anomalies or defects that may be causing excessive vibration. FFT analysis is also used in audio processing to analyze the spectral content of sound signals, and in image processing to analyze the frequency content of images.

Overall, FFT analysis is a powerful technique for analyzing the spectral content of signals and is used in a wide range of applications to identify patterns, detect anomalies, and extract information from signals in the frequency domain.

No. of flexures = 2, Natural Frequency = 5.86 Hz

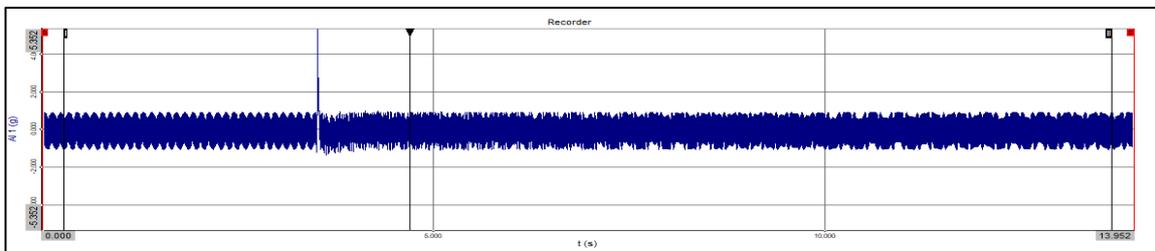


Fig. 5: Time domain for 2 flexures

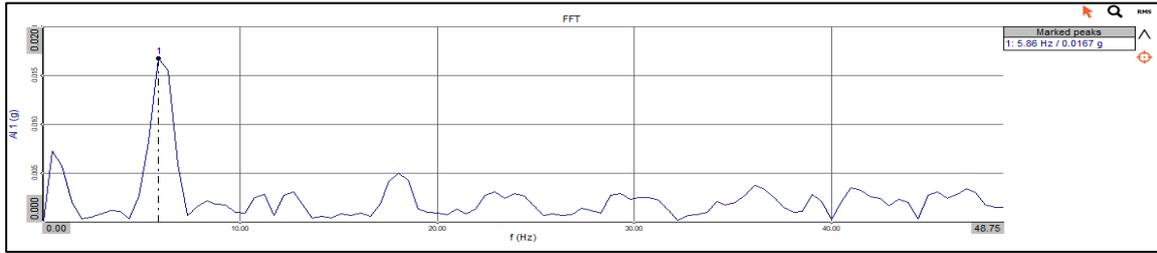


Fig. 6: Frequency domain for 2 flexures

3. Result

The study focused on examining a flexure bearing designed for use in ground applications through parametric analysis and modal analysis. Specifically, the researchers investigated various thickness parameters of the flexure and compared them to meet the criteria of high fatigue life and maximum stiffness. Using finite element analysis, the natural frequency was determined and plotted on a graph, revealing that as the frequency increased, the deformation and stiffness also increased.

No. of Flexures	Frequency (Hz)	
	ANSYS	FFT
2	4.82	5.86
4	5.87	8.30
6	7.89	10.25
8	8.86	11.47

Table 2: Comparison of result

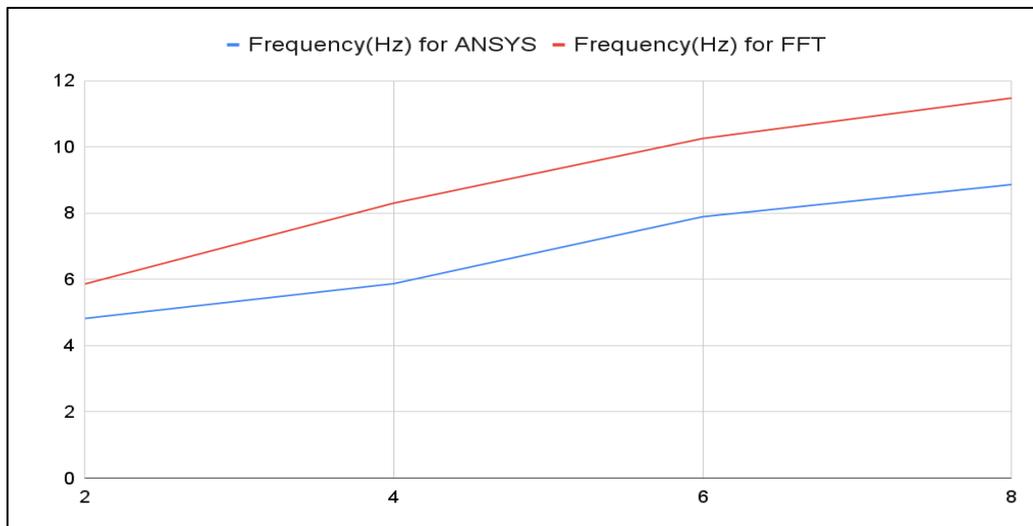


Fig. 7: Graph of Ansys and FFT results

4. Conclusion

1. The flexure spring was analyzed using ANSYS Workbench software to determine its modal characteristics. Natural frequencies were obtained for different configurations and materials. Experimental measurements of natural frequencies were also conducted using an FFT analyzer for ground applications. The results from ANSYS and the FFT analyzer were compared using graphs and tables.

2. The results can be used to optimize the design of flexure bearings for ground applications, ensuring their reliability and performance in demanding environments.

3. The availability of accurate modal analysis results is crucial for optimizing the design of flexure springs in ground applications. By knowing the natural frequencies, designers can ensure that the system operates away from resonance conditions, preventing excessive displacements and potential failures.

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