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Design and Test Evaluation of Cluster Dither for Inertial Measurement Unit with 3-Axis Ring Laser Gyroscopes

Cheonjoong Kim, Juneon An, Kyumin Shim
Agency for Defense Development, P.O. Box 35, Yuseong, Daejeon, South Korea

kcj3651@add.re.kr

Summary:
The purpose of this paper is to present a cluster dither design for applying continuous sinusoidal vibration to 3-axis RLGs simultaneously. Ring laser gyroscope (RLG) exhibits a specific range, known as the lock-in region, wherein the input angular velocity is too small to be measured. To mitigate the lock-in effect, a continuous mechanical sinusoidal vibration is applied to the body of the RLG, emanating from a dither mechanism. The proposed cluster dither design is verified through modeling and simulation (M&S). The validation of the proposed design is confirmed by test evaluation and manufacturing assessment.

Keywords: ring laser gyroscope, cluster dither, lock-in, natural frequency, sinusoidal vibration

Introduction

The RLG is a powerful tool to measure angular velocity. However, RLG has an inevitable deficiency caused by lock-in, where the input angular velocity is too small to be measured. To remove this lock-in region, the mechanical device called dither applies sinusoidal vibration to the RLG body. Generally, the dither is mounted at the center of the single-axis RLG body when the optical path length of an RLG is relatively large. However, if the RLG does not have enough optical path length, the mounting size for the dither in the quadrate RLG body is limited to inversely proportional to the square of the one-side length. This issue is a major concern in the dither design. To overcome this, this paper presents a new cluster dither design based on Ref [2], which can simultaneously apply mechanical sinusoidal vibration to 3-axis RLGs. The cluster dither is aimed to miniaturize an RLG-based inertial measurement unit (IMU). Results of the proposed design are verified through M&S. The performance of the proposed cluster dither is confirmed by manufacturing and test evaluation.

Cluster Dither Design

A conventional single-axis dither design is presented in Fig 1. As shown in Fig 1, the singe-axis dither is installed on the RLG housing using 3 fixing holes, and the RLG body is made to be fixed on the dither spoke. Thus, when any level voltage is applied to the PZT(pb-lead Zironcate Titanate) affixed to the dither spoke, the RLG body vibrates sinusoidally with a dither natural frequency and an amplitude corresponding to the voltage level applied to PZT. This physical structure of the dither highlights the natural frequency and the vibration amplitude as major design considerations. As depicted in Fig. 1, the dither spoke can be modeled as a cantilever beam [1]. Eq. (1) represents the natural frequency of the cantilever. Unfortunately, the cluster dither structure capable of simultaneously applying sinusoidal vibration to a 3-axis RLG deviates from the configuration depicted in Fig. 1. Furthermore, to install a 3-axis RLG on the cluster dither, some requirements should be fulfilled. First, 3 RLGs should be located at an interval of 120 degrees in the direction of dither rotation. Second, they are tilted at 54 degrees toward dither rotation. The cluster dither structure fulfilling such requirements is presented in Fig. 2. The dither spoke in Fig. 2 can be modeled as a cantilever, similar to the configuration depicted in Fig. 1. Which means that the cluster dither natural frequency can be obtained using Eq. (1). Following the selection of Invar as the material for the cluster dither and assuming an RLG with an optical path length of 10 cm, the required natural frequency to operate the RLG is determined to be 750 Hz. The final design of cluster dither is shown in Fig. 3. By using Eq. (1), the natural frequency of cluster dither is obtained as 783.57 Hz.

$$f_n = \frac{1}{2\pi}(\lambda L)_n^2 \sqrt{\frac{NEIL_f^2}{J_m L^3}} \qquad (1)$$

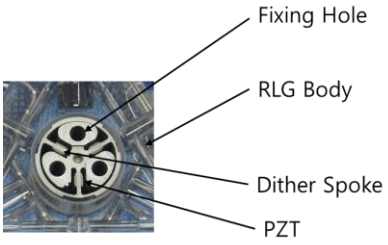

Fig. 1. The picture of typical single-axis dither.

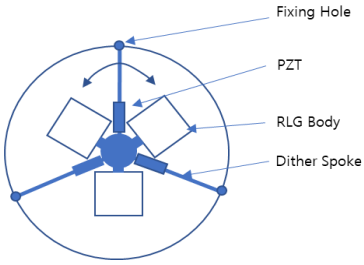

Fig. 2. The shape of cluster dither.

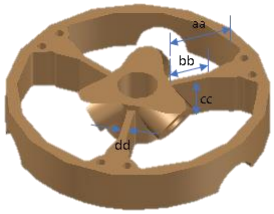

Fig. 3. The design result of cluster dither.

Cluster Dither Analysis and Test Results

To evaluate the proposed design validation, M&S is conducted using Solidworks. To verify the functionality of the cluster dither, the RLG body is modeled as a wheel-shaped structure with a moment of inertia equivalent to that of the RLG body. The M&S results are shown in Fig.4. The cluster dither natural frequency obtained in Fig.4 is 783.28Hz, which is almost the same as the theoretical frequency obtained from Eq. (1) implying theoretical natural frequency is reasonable. Further verifications using manufacturing and test evaluation have been carried out. The manufactured cluster dither is presented in Fig. 5. Fig. 5 shows the cluster dither installed in the center of the mounting fixture. The wheel-shaped structure as a replacement for the RLG is mounted on the cluster dither as depicted in Fig. 5. The manufactured cluster dither has an identical structure in Fig.4 except for the mounting part. The mounting part forms a square shape since the circular-shaped mounting part is hard to manufacture using existing machines. To confirm the performance of the dither structure, voltage range from 0 to 140V has been applied to the PZT. Then, the natural frequency of the manufactured cluster dither is measured. The measurement results in Fig. 6 shows that the cluster dither natural frequency is between 732 and 746Hz depending on the PZT voltage.

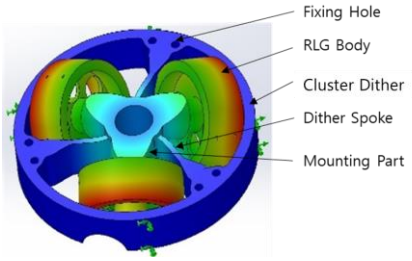

Fig. 4. The M&S result of cluster dither.

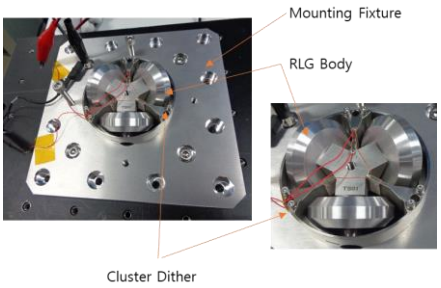

Fig. 5. The manufactured result of cluster dither.

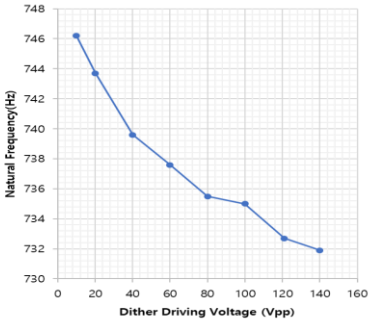

Fig. 6. The test result of cluster dither.

The natural frequency obtained from Eq. (1) and M&S is approximately 40Hz higher than the natural frequency in Fig.6. The difference in the natural frequency between the manufactured dither and the M&S modeled dither is caused by weight change and the mounting part shape difference during actual dither manufacturing.

Conclusion

This paper introduces a cluster dither design capable of simultaneously imparting continuous sinusoidal vibration to 3-axis RLG. The validation of the proposed cluster dither design has been conducted through M&S, test evaluations and manufacturing assessments. The results confirm the proposed design is valid.

References

[1] Lee, D. C., Moon, G., & Lee, J. C., Mechanical Dither Design for Ring Laser Gyroscope, KSME Int. J., 16, 481-491(2002); https://doi.org/10.1007/BF03185078

[2] J. G. Hanse, Cluster Dither Apparatus, U.S. Patent 5173745, 1992.