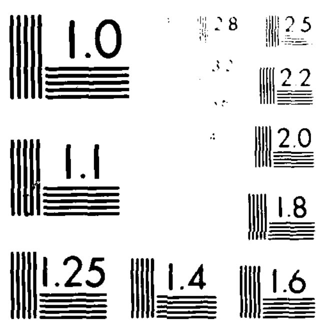
AD-A112 129 ARMY MISSILE COMMAND REDSTONE ARSENAL AL GUIDANCE A--ETC F/G 17/7
WHEEL-SPEED INDUCED ERRORS IN THE USE OF DRY-TUNED GYROS.(U)
AUG 81 J C HUNG, H V WHITE

UNCLASSIFIED DRSMI/RG-81-16-TR SBI-AD-E950 209 NL

1 OF 1
AD A
112129

END
DATE
FILMED
04-82
DTIC



MICROCOPY RESOLUTION TEST CHART

(2) AD-E950 209

ADA112129

TECHNICAL REPORT RG-81-16

WHEEL-SPEED INDUCED ERRORS IN THE USE OF DRY-TUNED GYROS

J. C. Hung and H. V. White
Guidance and Control Directorate
US Army Missile Laboratory

August 1981

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35898

Approved for public release; distribution unlimited.

DISPOSITION INSTRUCTIONS

DISCLAIMER

TRADE NAMES

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TR-RG-81-16	2. GOVT ACCESSION NO. AD-A112 129	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Wheel-Speed Induced Errors in the Use of Dry-Tuned Gyros		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J. C. Hung, H. V. White		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Commander, US Army Missile Command, ATTN: DRSMI-RG, Redstone Arsenal, AL 35898		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Commander, US Army Missile Command, ATTN: DRSMI-RPT, Redstone Arsenal, AL 35898		12. REPORT DATE August 1981
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Dry-tuned gryos
dual gyro wheel supply

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

It is known that for a gimbaled inertial measurement unit employing two dry-tuned gyros, a dual gyro wheel supply gives better performance than a single gyro wheel supply. The effectiveness of the dual gyro wheel supply is explained in this paper by demonstrating the efforts of certain vibrations on gyros. It will be shown that a dry-tuned gyro is susceptible to vibrations at frequencies which are either equal to or twice that of the gyro spin frequencies. By using two power supplies of slightly different frequencies, external vibrations at these frequencies are avoided. It is recommended that gyro sensitivities with

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

respect to external vibrations at these special frequencies be included in the performance specification of a dry-tuned gyro.

CONTENTS

I. INTRODUCTION

Dry-tuned gyros have been widely used in recent years as inertial sensors for angular motion. This type of gyro possesses an important feature which is not shared by other types of mechanical gyros, namely, absence of bearings for supporting the precession axis. Therefore, bearing friction induced drifts do not exist. In addition, they can be made to provide a sensing range up to 400 degrees per second, considerably higher than that of other types of mechanical gyros having the same linearity. A third attractive feature of this type of gyro is its simple and rugged construction which allows it to be low-cost as compared to other types of gyros of similar performance.

However, dry-tuned gyros also have their inherent weaknesses. The first weakness is their sensitiveness to the disturbances which are at their respective spin frequencies. In a conventional mechanical gyro, the spinning wheel provides an angular momentum which, when interacting with an angular rate input, produces precession. In a dry-tuned gyro, the spinning wheel not only provides angular momentum, but also generates a carrier of frequency N, the spin frequency. The carrier is modulated by the tilt of the rotor in response to a rotation of the gyro case about an axis parallel to the rotor plane. Pickoffs, which are case-fixed, not only sense the rotor tilt, but also serve as phase-sensitive demodulators to separate the tilt signal from the carrier. The modulation feature makes the gyro sensitive to external vibrations which are at the spin frequency.

The second weakness of dry-tuned gyros is the existence of the so-called "2N noise," which is an unwanted signal of twice-spin frequency. This signal is caused by the structural dynamics of the gyros. Minimization of the 2N noise is one of the important considerations in dry-tuned gyro design.

A third weakness in this type of gyro is the sensitiveness to external vibrations at twice spin frequency. These vibrations, when interacting with the rotor spin motion, may create rectification effects resulting in gyro drifts.

The inherent weaknesses of the dry-tuned gyros limit them from being rate sensors of very high precision. A drift stability of .005 degree per hour is probably the best one can achieve.

An interesting phenomenon has been observed from the use of a pair of dry-tuned gyros on a gimbaled platform of an inertial measurement unit (IMU). When two separate power supplies of slightly different frequencies are used each driving the wheel of one gyro, the performance of the IMU is better than that when only a single power supply is used to drive both wheels. The former implementation has been called dual gyro wheel supply (DGWS) and the latter single gyro wheel supply (SGWS). This phenomenon has not been noticed in the uses of conventional mechanical gyros. The causes of such a phenomenon have not been well understood, but are of considerable interest to users of dry-tuned gyros. The study reported in this paper was aimed at exploring these causes. The goal was to achieve a physical understanding of the phenomenon.

II. QUALITATIVE ANALYSIS

In general, when a gyro wheel is spinning at a speed of N revolutions per minute, there are vibrations of frequency N cycles per minute (cpm). This is due to the ever existing mechanical imbalance of the gyro wheel and possibly the electromagnetic imbalance of the magnetic field in the gyro motor. For a dry-tuned gyro, the wheel rotation induces not only vibrations at the spin frequency but also at the twice-spin frequency. These vibrations may be in the form of rotational motions as well as translational motions. Then two dry-tuned gyros are mounted on the same platform, the vibrations generated by one gyro become the disturbance input to the other, and vice versa. Therefore, the problem of concern reduces to the study of the effects of vibrations of spin and twice-spin frequencies on a dry-tuned gyro.

Figure 1 represents the geometry of a dry-tuned gyro, where X, Y, and Z axes of a coordinate system are case fixed. The Z-axis is coincident with the spin axis. The X and Y axes are perpendicular to the spin axis and, loosely speaking, is in the rotor plane. Each vector of vibration, rotational or translational, may be resolved into two components, one along the spin axis and the other in the rotor plane. Figure 2 shows a classification of various vibrations which can affect the performance of the gyro. Each class of vibrations will be discussed in turn in the sequel.

A. Translational Vibration in Rotor Plane at 2N Frequency

If the gyro's gimbal exhibits pendulosity in a direction perpendicular to the spin axis, translational vibration at twice-spin frequency in the rotor plane will cause gyro drift. Figure 3 shows the top view of the geometry of a dry-tuned gyro's rotor-gimbal-shaft assembly. Assume a translational vibration at a frequency of 2N along the X-axis. If the gimbal construction is not ideally balanced, the pendulosity of the gimbal will force the gimbal to tilt. The tilt action of the gimbal, transmitted via the pair of outer flexures, forces the rotor to tilt. The wheel position where the gimbal's pendulosity effect on rotor is maximum occurs when the axis of outer flexures is in the direction of translational vibration as shown in Figure 3(a). On the other hand, the wheel position for minimum effect of gimbal pendulosity on the rotor is shown in Figure 3(b). When the frequency of translational vibration is twice that of wheel rotation the net tilt of the rotor due to gimbal pendulosity is not zero, which contributes to a gyro drift error. If more than one gimbal are used, their respective pendulosities can be adjusted for zero net tilt of the rotor.

B. Translational Vibration along Spin Axis at N Frequency

When the rotor-gimbal assembly exhibits pendulosity along the direction of the spin axis, translational vibration at the spin frequency along the spin axis will produce a constant tilt of the wheel. Figure 4 shows the side view of the geometry of a wheel and shaft. One can visualize that if the gyro wheel is spinning at N rpm and if the vibration along the spin axis is at N cpm, then the center of mass of the rotor-gimbal assembly experiences a constant force at each angular position around the spin axis. The result is a constant tilt of the assembly, producing a constant gyro drift.

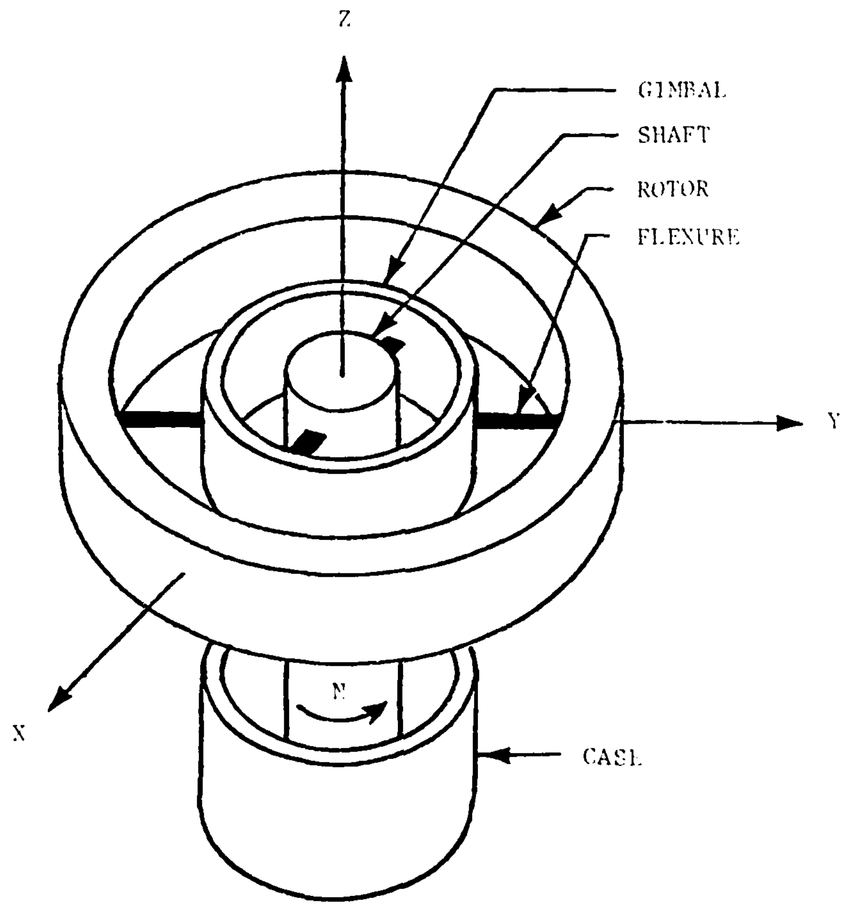
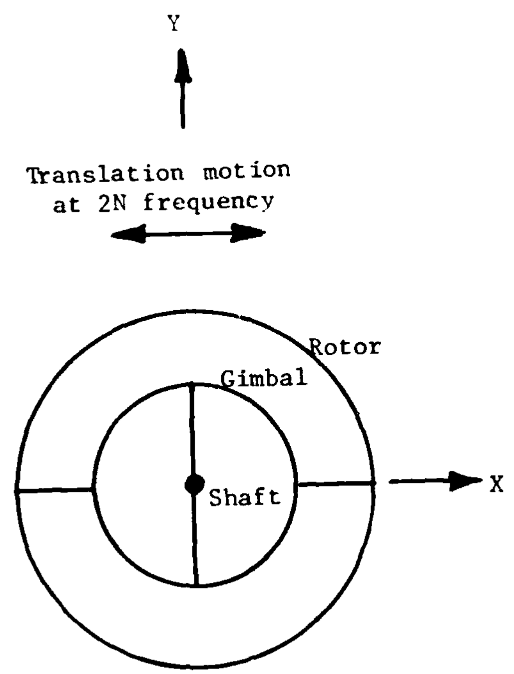


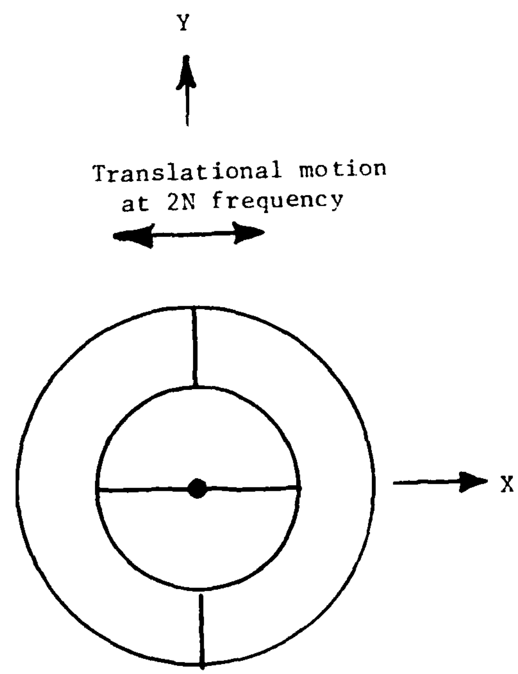
Figure 1. A dry-tuned gyro configuration.

- External vibrations
  - Translational vibrations
    - Vibrations in the rotor plane:
      - Twice-spin frequency
      - Due to gimbal pendulosity
    - Vibrations along spin axis:
      - Spin frequency
      - Due to wheel pendulosity
  - Rotational vibrations
    - Vibrations in the rotor plane:
      - Twice-spin frequency
      - Due to gyro structural property
    - Vibrations along spin axis:
      - Spin frequency
      - Due to wheel pendulosity

Figure 2. Classification of external vibrations causing gyro drifts.



a. Position of maximum effect of gimbal pendulosity on rotor



b. Position of minimum effect of gimbal pendulosity on rotor

Figure 3. Rotor-gimbal-shaft geometry for translational vibration in the rotor plane.

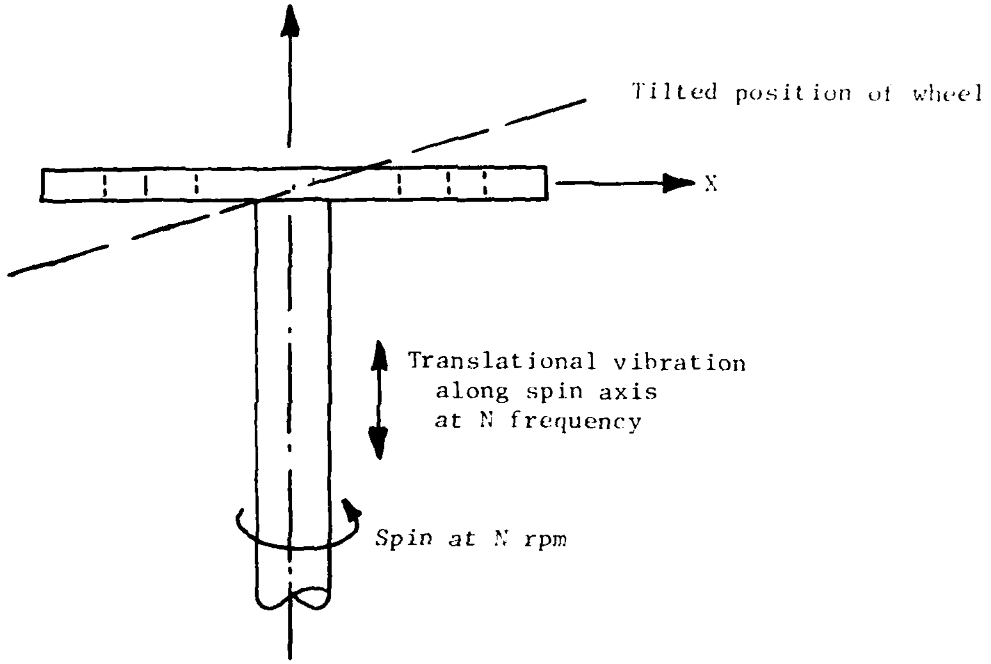


Figure 4. Rotor-gimbal-shaft geometry for translational vibration along spin axis.

C. Rotational Vibration in Rotor Plane at 2N Frequency

Consider the effect of a rotational vibration at the twice-spin frequency where the vector of vibration lies in the rotor plane (or XY-plane). This effect is not pendulous, but is due entirely to the structural property of the gyro wheel.

Refer to Figure 5 and let the rotational vibration be in the X-direction. The figure shows the relationships among the waveform of the rotational vibration, the rotation of the gyro wheel, and the tilt of the rotor plane. Notice that for a single rotation of the gyro wheel (going through positions 1, 2, 3 and 4 in Figure 5(b)) the rotational vibration makes two cycles as shown in Figure 5(a). Beginning with position 1, the inner flexures are in a rigid state with respect to the case rotation about the X-axis. In the meantime, the rotational vibration is in a backward direction along the X-axis. Notice that the position of two outer flexures are is in a position to make rotor and gimbal as one rigid piece as far as rotation about the X-axis is concerned. The load of two inner flexures at this position is much larger than the load of two outer flexures at position 1. Therefore, the gimbal and rotor are torqued backward only very slightly. The backward tilt of the rotor at position 2 is much smaller than its forward tilt at position 1. The actions of the gyro wheel in positions 3 and 4 are similar to those of positions 1 and 2, respectively.

Figure 5(c) shows the waveform of rotor tilt in response to the vibration. The waveform resembles a half-wave rectification. From the above discussion, one sees that more complete half-wave rectification results if the moment of inertia of the gimbal is increased. Elimination of the rectification is achieved by reducing the moment of inertia of the gimbal to zero, an impractical proposition. In practice, the desired moment of inertia of the gimbal is primarily dictated by the tuning condition of the dry-tuned gyro. It is conceivable that the rectification effect can be reduced, or even eliminated, by adopting a multi-gimbal construction. The d-c component of the rotor tilt contributes to the gyro drift caused by the twice-spin frequency rotational vibration in the rotor plane.

D. Rotational Vibration along Spin Axis at N Frequency

A rotational vibration at the spin frequency along the spin axis also causes gyro drift. The effect is due to the pendulosity of the gyro wheel, including both the rotor and gimbal, in the direction perpendicular to the spin axis. Figure 6 helps to explain the phenomenon. If the center of mass, CM, of the gyro wheel is off the center of the wheel rotation, it experiences an inertial force when the wheel rotation contains a vibratory component. This inertial force is alternating in direction with respect to the rotating wheel at the frequency of the vibration. When the frequency of vibration equals the spin frequency, a mechanical full-wave rectification is formed. Under this condition, CM experiences a net inertial force in a case fixed direction. The case fixed direction is illustrated as the X-direction in Figure 6. The conditions of the two half-cycles of the vibration are shown in Figures 6(a) and 6(b), where α indicates the rotational acceleration of the vibration. Also shown is the case fixed full-wave rectified inertial force f. This force produces a tilt of the rotor in a case fixed direction, resulting in a gyro drift.

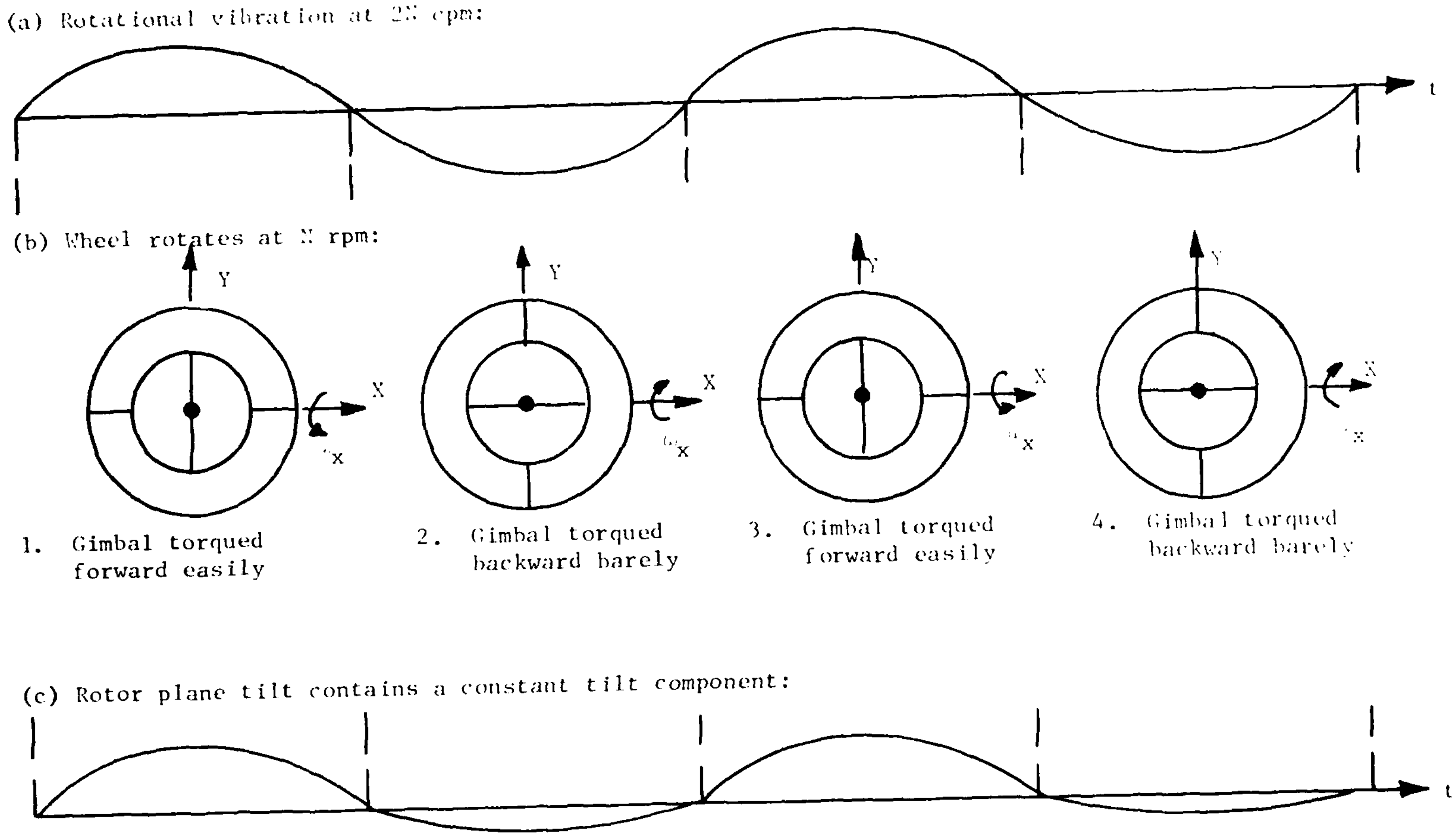
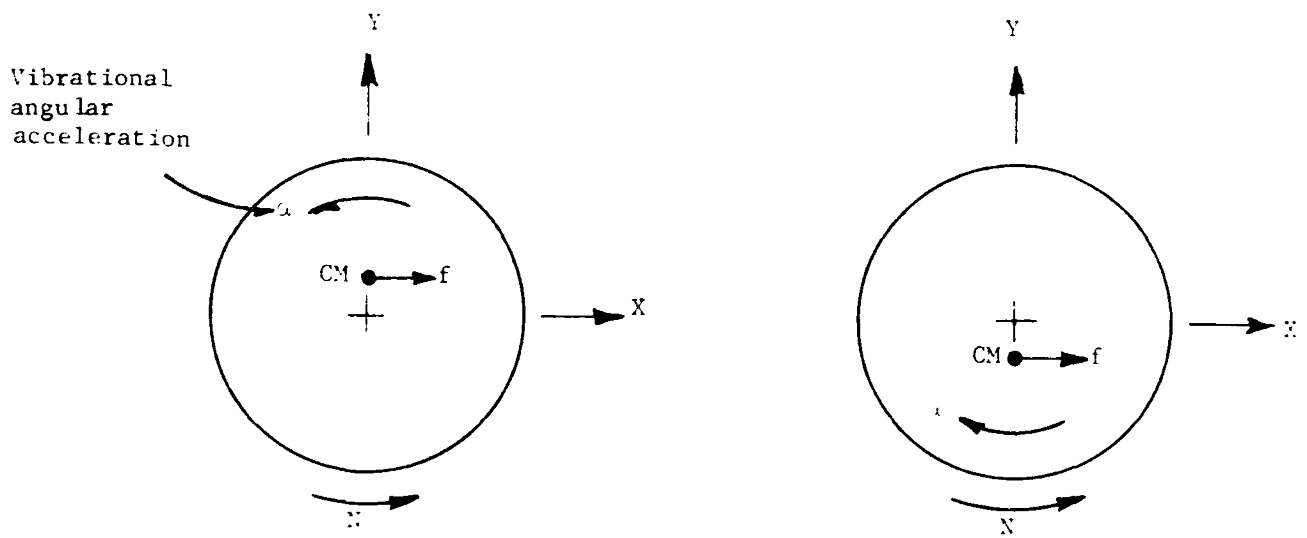


Figure 5. Wheel geometry for rotational vibration at twice-spin frequency in the rotor plane.



a. First half cycle of the vibration

b. Second half cycle of the vibration

Figure 6. Wheel positions for rotational vibration at spin frequency along spin axis.

III. CONCLUSION

The question of "why DGWS gives better performance than SGWS for an IMU employing dry-tuned gyros" has been answered qualitatively by revealing the effects of various vibrations on gyros. It has been found that a dry-tuned gyro is particularly susceptible to vibrations at frequencies which are equal to its own spin and twice-spin frequencies. By using separate power supplies of slightly different frequencies, external vibrations for each gyro at its own spin and twice-spin frequencies are avoided.

The use of two power supplies of slightly different frequencies implies that one or both of the two dry-tuned gyros on the gimbaled platform is operating at an off tuned condition. This may not be a problem for two gyros. However, for a platform using a large number of redundant gyros to improve the system reliability, and a large number of power supplies, all at different frequencies, may cause problems in hardware instrumentation and in gyro off-tuning.

Usually, those gyro pendulosities mentioned in earlier discussion are unknown quantities. From the users point of view, pendulosites of a gyro and various moments of inertias are not adjustable. Therefore an analytic representation of the phenomenon studied will not be very useful. However, users will find it very useful if the sensitivities of each dry-tuned gyro with respect to the spin and twice-spin frequency vibrations are included in the gyro performance specification. Gyro manufacturers can obtain these sensitivities by product testing. The recommended sensitivities include:

1. Sensitivity to translational vibration in the rotor plane at 2N frequency.

2. Sensitivity to translational vibration along spin axis at N frequency.

3. Sensitivity to rotational vibration in the rotor plane at 2N frequency.

4. Sensitivity to rotational vibration along spin axis at N frequency.

The unit for these sensitivities should be "drift per unit vibration amplitude." Such kind of sensitivity information will enable users to evaluate the suitability of a typical gyro for a certain application and the needed complexity of the gyro wheel power supply.

REFERENCES

1. Howe, E. W. and Savet, P. H., "The Dynamically Tuned Free Rotor Gyro," in Stable Platform and Inertial Components, McGraw-Hill Inc., 1964, 49-54.

2. Craig, R. J. G., "Theory of Operation of an Elastically Supported, Tuned Gyroscope," IEEE Trans. on Aerospace and Electronic Systems, Vol. AES-8, No. 3, 1972, 280-288.

3. Craig, R. J. G., "Theory of Errors of a Multigimbal, Elastically Supported Tuned Gyroscope" IEEE Trans. on Aerospace and Electronic Systems, Vol. AES-8, No. 3, 1972, 289-297.

4. Craig, R. J. G., "Dynamically Tuned Gyros in Strapdown Systems," AGARD Conference Proceedings No. 116, Inertial Navigation Components and Systems, 1973.

5. Hung, J. C. and Doran, B. J., "High Reliability Strapdown Platform Using Two-Degree-of-Freedom Gyros," IEEE Trans. on Aerospace and Electronic Systems, Vol. AES-9, No. 2, 253-259.

6. Tsuei, Y. C. and Hung, J. C., "New Development in High Reliability Strapdown Platform Using TDF Sensors," Proceedings of 1974 Joint Automatic Control Conference, American Institute of Chemical Engineering, New York, 1974, 83-91.

DISTRIBUTION

	No. of Copies
Commander US Army Materiel Development and Readiness Command	
ATTN: DRCRD	1
DRCDL	1
5001 Eisenhower Avenue Alexandria, VA 22333	
The University of Tennessee Department of Electrical Engineering	
ATTN: Dr. J. C. Hung	1
Knoxville, TN 37916	
NASA Johnson Space Center EG5	
ATTN: Mr. Malcolm Jones	1
Houston, TX 77058	
IIT Research Institute	
ATTN: GACIAC	1
10 West 35th Street Chicago, IL 60616	
DRCPM-PE-EA, Mr. Wagner	1
Mr. Bond	1
Mr. Armstrong	1
DRSMI-LP, Mr. Voight	1
-R, Dr. McCorkle	1
-RG	1
-RGL, Mr. White	5
-RGN, Mr. McLean	1
-RPR	5
-RSL, Mr. Bounds	1
-RPT, Record Copy	1
-RPT, Reference Copy	1

DATE

ILME