Mitigation of Military High Shock Transients for Shipboard Gyrocompass with Fiber Optic Gyros (FOG)

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ABSTRACT

Litton Marine Systems is currently manufacturing the first generation of marine Attitude and Heading Reference System (AHRS), MK27F, using the LN-200 Fiber Optic Gyro (FOG) Assembly. As a replacement to legacy Sperry Gyrocompass System MK27, the MK27F will be the main and/or the backup-heading compass for thousands of naval ships worldwide. This new product will satisfy stringent military shock and vibration requirements. Unlike Ring Laser Gyro (RLG) low fragility levels (Max 50 g), the LN-200 Fiber Optic Gyro Assembly can be exposed to levels as high as 90 g. The initial developmental effort reduces the overall weight and the physical dimension of the new AHRS while maintaining the same performance characteristics of its predecessor, the MK27. This paper addresses the shock transient mitigation for shock requirements specified by MIL-S-901D. Comparisons between predicted and measured response are provided for a single strut as well as the fully shock isolated platform. Development and implementation of a test technique, fixturing to identify single shock strut performance, and the feasibility in meeting overall system design goals are discussed. Analytical and experimental results are presented to demonstrate the effectiveness of the MK27F Shock Absorber basic design for MIL-S-901D LWSM while predicted response is presented for the floating platform Heavy Weight Shock Machine (HWSM).

INTRODUCTION

There are over 2500 legacy MK27 Gyrocompass systems installed worldwide on U.S and International Navy's vessels Fig. 1. The 96 lbs Gyrocompass contains a gyroscope, which is controlled to make it seek true north. This is accomplished by employing gyroscopic inertia, gyroscopic precession in combination with earth rotation and gravity effect. The equipment was designed in the early sixties to meet stringent military environmental requirements for shock MIL-S-901Grade A, Class I and Type A, Vibration (MIL-STD-167-1), EMI/RFI (MIL-STD-461) and Submersion under three feet of water per MIL-STD-810. As a Gyrocompass System, the MK27 provides ship's Heading reference within an accuracy of 0.5° secant latitude static and 1.5° secant latitude dynamic.

There are a number of drivers to replace the legacy MK27 using new technologies that lend themselves to low cost COTS, compact and more power efficient design package. The legacy MK27 Gyrocompass equipment consists of a Master Compass that houses a fluid suspended spinning mass gyro. Both the spinning mass gyro and the Master Compass Assemblies are extremely labor intensive to build and utilize obsolete technologies and costly components. The Electronic Control Unit Assembly contains a large number of components and is also labor intensive to build.

The requirements for a replacement of the legacy MK27 are that it meets its predecessor's performance accuracy as well as the military environmental requirements or better. In late 2000, developmental work started on the first generation ship's gyrocompass system using new generation of FOG Inertial Measurement Unit (IMU), the Litton G&C LN-200. The LN-200 IMU contains three Fiber Optic Gyros (FOG) in a cluster arrangement, three silicon accelerometers, and sensor electronic assembly. The gyro and the silicon accelerometer axes are mutually orthogonal in the LN-200 assembly. For the MK27F (Fig. 2) to meet the Heading accuracy, the IMU with its sensor element is indexed about the vertical axis to average the gyro bias errors of the two horizontal FOG sensor outputs. To index the IMU, a gearbox assembly with 36:1 reduction using COTS Stepper Motor and Encoder assemblies was designed.



Fig. 1. Litton Marine Systems Legacy MK27 Gyrocompass System: 96.0 Lbs., 1.8 ft³



Fig. 2. Litton Marine Systems MK27F (FOG) AHRS: 50.0 Lbs., 1.45 ft³

A shock isolation system design capable of achieving IMU returnability after shock events to within 0.2° is therefore required to provide a stable platform for the LN-200 IMU and protect the COTS gearbox elements. The same isolation system is required to mitigate the external shock transients to fragility levels well below 90 g's to insure that the LN-200 IMU and the Encoder Assemblies survive and maintain performance accuracy.

The present work follows the same test methodology presented by Lahham, et al [1] in assessing the new miniature shock strut element. The validation of the optimized strut parameters (stroke, preload and damping) is then followed by a full-up analysis and shock testing as required by Mil-S-901D. As demonstrated in [1], the efficiency of the two-step approach is stressed by eliminating troubleshooting with a live full-up system.

SYSTEM ARCHITECTURE AND FUNCTIONALITY

MK27F Enclosure Cabinet Unit

The MK27F enclosure is a $12^{\circ}x12^{\circ}x21^{\circ}$ shock ruggedized investment casting that incorporates cooling fins (fig. 2). The shock and vibration isolated electronics and LCD display are easily accessible from the top of the enclosure. The Enclosure is fastened to the ships deck using the same mounting hole pattern of the legacy MK27 and associated hardware. A number of finite element analysis iterations were performed to optimize the structural rigidity of the enclosure. Fig 3 depicts the first three normal modes of the Enclosure (right illustration) and the Electronic Assembly as mounted to the Cover (left illustration). Note that the lowest resonance of 59 Hz is outside MIL-STD-167-1 forcing frequency range (5Hz – 50 Hz), which keeps the transmissibility to minimum.



Fig. 3. MK27F Enclosure Assembly Normal Mode Analysis Lowest three modes of vibration (a) Depicts Electronic Assembly as mounted to the Cover without Enclosure, (b) Enclosure with Cover

IMU PLATFORM DESCRIPTION

The Inertial Measurement Unit shown in Fig. 4 consists of the LN-200 mounted to a finned (heat sink) turntable. The low profile Gearbox Assembly (not shown) is mounted to the bottom of shock isolation system interface plate. Six shock struts comprise the isolation system in a hex pod pattern. The IMU and the indexer Assembly is balanced by design about all three principal axes.

Gearbox Indexing Assembly

To meet the performance accuracy, a single axis 36:1 reduction Gearbox Assembly was incorporated to average the horizontal gyro bias errors for the LN-200 IMU. The Gearbox Assembly is a rugged construction in which a half-inch main shaft is precision aligned by two concentric bores of tight running tolerance. Captive to the main shaft is an anti-backlash gear assembly. The rotating payload is shimmed axially to eliminate unwanted axial play. The COTS stepper motor, encoder and oil-impregnated bronze bushings are used instead of expensive torque motor, resolver and bearings. This mechanical design is easily calibrated to the reference installation axes. The IMU platform calibration allows for the computation of corrected heading, roll, and pitch attitude while the gearbox is rotating or held at any position.

Shock Isolation System Design

As mentioned above, the Shock Isolation System is comprised of 6 individual shock struts arranged in a hex pod pattern. Similar systems have been in use for previous Inertial Navigation Systems (INS) within the U.S. and NATO Naval Fleets for many years [1,2]. The struts employed within these existing systems are of the high-pressure hydraulic type. Due to the size, weight, and cost constraints of the new MK27F, however, a new isolator design was necessary. This is due to the fact that hydraulic

components do not linearly scale with respect to the peak translational dynamic force of the strut or the mass of the isolated IMU and Indexer Assembly. For small isolated masses, high-pressure struts become impractical due to scaling problems. The isolated mass of the MK27F IMU and Indexer Assembly is only 7 pounds, an order of magnitude lighter than the previous MK49 and MK39 Assemblies.

Shock struts for navigation systems and Gyrocompasses require strict adherence to specified characteristics. In particular, the damping function, spring preload and spring rate need to be consistent in order to guarantee an optimized isolation system over the entire range of typical shock inputs and throughout the operating temperature range.



Fig. 4. MK27F Shock Isolated IMU Platform



Fig. 5. Taylor Devices Tension-Compression Coil Spring Stiffness and Liquid Damper Strut Assy.

Of prime importance is the ability of the isolation system to return the IMU Assembly to its original position after a shock event. Typical INS shock struts require tight returnability along the length of each of 6 struts. These shock strut characteristics need to be preserved for the new MK27F gyrocompass, while remaining within the cost and size constraints specified.

The new shock strut contains a "caged" coil spring that is pre-compressed to a given spring preload (Fig. 5). This preload will fix the gyrocompass in a rigid position throughout the vibration environment as specified in MIL-S-167 and will also deflect and return the system to its initial position within the required .0001 inch after a shock input per MIL-S-901D. Because the coil spring is manufactured using CNC machinery, its helix angle and end constraints can be controlled to tight tolerances. An internal, bi-directional mechanism allows identical spring characteristics in either direction of motion. Precision machined components and match fitted parts of the struts will guarantee the accuracy of the AHRS system throughout the specified shock and vibration environment.

An internal fluid filled pressure cylinder provides the required level of damping in either direction of motion. Specific orifice patterns are machined into the damping head to provide a specific damping function. These specific orifice configurations coupled with tight machining tolerances result in consistent isolator performance over the specified shock environment and operating temperature range. Under shock, the isolator will begin to stroke after the preload is exceeded, exercising the effective coil spring rate, which is position dependent, and thus conservative, and the damping, which is velocity dependent, and thus dissipative. While the effective coil spring rate is essentially linear over the stroke, the damping can be highly nonlinear, and can be represented as C^*V^{α} , where C is the damping coefficient, V is velocity and $^{\alpha}$ is the damping exponent.

The shock strut developed for the MK27F measures 6.0 inches in length and weighs approximately .50 pounds. Patents are pending on the device.

Selection of Controlled & Repeatable Shock Test Input

A controlled shock test was used as a calibration tool. This test used a Ling Electrodynamic shaker to generate a 30 g, 11ms half sine pulse. This test method provided a speedy check of the gains/calibration and data acquisition for both the single strut and the IMU platform. Proven techniques for shock strut optimization were presented in [1]. By using these techniques the transients of all state variables, acceleration, velocity and displacement are measured at the input and the isolated payload thus providing an understanding of the single strut and platform behavior. For a pure uni-axial shock input, the shaker is the ideal mechanism to evaluate and define the baseline of a single strut characteristics. The Data Acquisition System and Software used consists of 32 Channels TEAC RX-832 Data Recorder, Puma Spectral Dynamics analyzer, Khron Filter and an in-line Signal Conditioner double integrator Model 483B20 for velocity and displacement response by PCB Piezotronics.

Single Strut Fixture Optimization

Following the single strut initial testing on a Ling shaker at Sperry Systems Test Facilities in Charlottesville, Virginia, unexpected behavior was observed as illustrated by the spiked data shown in Fig. 6. Considering the single strut test article, it was suspected that such behavior is an artifact of the fixture rigidity and the mounting orientation to the shaker. In Fig. 7 the test article was subjected to the input pulse with the shaker head in the vertical position. To insure fixture rigidity with the natural fundamental frequency comfortably high, a Finite Element model was generated. The normal mode analysis of the fixture configuration machined prior to the analysis yielded low frequency resonance (484 Hz) when fixed at the base and as shown by Fig. 7. The Fixture resonance when mounted in the



Fig. 6. MK27F Single Strut Accel. Response with inherent Fixture resonance when subjected to 30g, 11ms Half Sine Pulse

up-right position (see Fig. 8(a)) resulted in undesired Fixture-Strut interaction. Change in holding Fixture geometry and attachment to the shaker resulted in a shift of the fundamental resonance from 484 Hz to 4950 Hz (Fig. 8(b)). For a typical acceleration input of 30 g, the holding fixture dynamic response can be at a desired low level of $5E10^{-5}$ inches in the region of the moving dummy mass along the thrust axis of the strut.

Single Strut Test

To validate the model of the isolator, a single strut was tested on the Ling shaker with dummy supported weight of 2.8 lbs. The weight of 2.8 lbs used in this test was based on the worst-case equivalent force a strut would see under the MIL-STD-167-1 vibration environment. A series of approximate 30g, 11 ms half sine pulses were then applied along the isolator thrust axis. Figure 9 illustrates the details of single strut test setup and the accelerometer locations. Initial test trials on a pilot strut assembly indicated limited travel due to high damping force. This is a conservative manufacturing approach that allows a buffer in the pilot strut unit to further tune the orifices design. The first iteration of testing and tuning the pilot strut unit, resulted in reducing the damping force by 40% from the initial configuration. The pilot strut assembly was then subjected to a bi-directional pulse of 30 g, 11 ms half-sine. Both directional results of the supported weight acceleration and travel are overlaid in Fig. 10. The ideal match of the

mass response (magnitude and phase) when the strut is in compression or tension is a technical and manufacturing achievement. The identical behavior that the struts exhibit along both thrust axes, make this novel miniature strut assembly design highly suitable for the MK27F Gyrocompass application.



Fig. 7. Shaker Test Setup for Single Strut Evaluation

Dummy Payload Mass (2.8 Lb) -

Fig. 8. Fixture Finite Element Model(a) Initial Test Fixture Configuration(b) Modified Test Fixture Configuration

MK27F Strut



Fig. 9. Single Strut Test Setup



Fig. 10. Single Strut SN002 Tension/Compression Overlay Response (a) Accel., (b) Travel

Single Strut Simulation Model

The actual acceleration time history was captured for each test and used as input to the mathematical model. Fig. 11(a) shows an overlay of the payload acceleration test results vs. that of the predicted. This plot shows good agreement in terms of amplitude and phase. Differences may be due to the test weight's own natural frequency and/or any clearance between the test fixture and the isolator that may induce a wobble. A comparison of the twice-integrated acceleration difference between the input and output accelerometers and the predicted stroke shown in Fig. 11(b) indicates very good agreement in terms of both amplitude and phase.

Using the information gathered in the single strut tests, it was determined to proceed with the six-strut system set to the parameters (i.e. preload, spring rate, and damping) used in the single strut tests.

Prior to a full-up system test, it was essential to evaluate all six struts individually to discover any fabrication anomalies. A sequence of bi-directional 30g, 11ms halfsine pulses were then conducted on each strut to examine strut repeatability to itself as well as to the other struts making up the isolation system. The Payload Acceleration and Stroke are overlaid for all six struts in Fig. 12 and Fig. 13 for tension and compression cycling of the coil spring. The Stroke is computed as the difference between the measured Fixture and the



Fig. 11(a). MK27F Single Strut: 30 g Input Accel. Response Overlay of Test and Predicted Data



Fig. 11(b). MK27F Single Strut: 30 g Input Accel. Response Overlay of Actual and Predicted Isolator Stroke

Payload displacement for the particular event. The test results illustrate the repeatability and consistency of the response (magnitude/phase) for the six struts when cycled in tension and compression. The maximum variation of the Payload peak accelerations for either tension (Fig. 12(a)) or compression (Fig. 13(a)) were within 15% while the stroke results shown in Fig. 12(b) and Fig. 13(b) varied as high as 20%.



Fig. 12. 30 g, 11ms Half Sine Pulse Response of MK27F Single Strut in Tension (a) Accel. (b) Stroke

Fig. 13. 30 g, 11ms Half Sine Pulse Response of MK27F Single Strut in Comp. (a) Accel., (b) Stroke.

(1)

Dynamic Model

The model of the a single tension/compression isolator for the single strut tests is based on the following equation:

 $FS = PL + K x + C*V^{\alpha}$

Where,

- FS External Load
- PL Isolator Preload
- K Coil Spring Rate
- V Velocity
- C Damping Coefficient
- ^α Damping Exponent
- x Payload Motion

The model of the hexapod system is a full rigid body, six degree of freedom model (three translational and three rotational), utilizing the above dynamic equations to represent each of the six struts. Payload motion was resolved into strut motion through vector algebra, as well as the effective force and moments about the center of gravity. The main assumptions in this model are that the entire payload mass can be represented as a single rigid body, and that the base input motion is entirely translational (i.e. no rotational motions).

Full-Up System Test: 30g Pulse in Front-to-Back Direction

A model of the full system was subjected to a series of 30g half sine pulses in the front-to-back (horizontal) plane, the softest isolation direction of the system. This direction was expected to yield the most payload travel owing to the steep inclination (56°) of the isolators with respect to the horizontal plane. The acceleration input used in the test was used in the model of the system. The acceleration results are shown in Fig. 14, while a comparison of the system travel is shown in Fig. 15.

While the accelerations are slightly off in phase, the overall signatures are quite similar, although the first peak amplitude differs by 20%. This may be due to picking up an un-modeled resonance at the system mass in the test results, since the model is a hypothetical rigid body representation. As is seen in the system travel, the phasing is almost exact while the amplitudes are greater in the test results than in the predicted. This discrepancy may be due to the double integration of the accelerometer data of two channels to get the stroke displacement. Thus carrying the differences seen in acceleration between the test and the model. Also, the rigid body model travel is measured at the hypothetical center of gravity of the model, while the test accelerometer is three inches above the center of gravity. Thus any rotational motion of the payload will be measured by the accelerometer and integrated.

1

0.8

0.6

0.4

0.2 0

-0.2

-0.4

-0.6 -0.8

0

0.1

Travel (inches)





Shock Isolation System Behavior under Bi-Directional Inputs (Front-to-Back Axis)

The IMU platform (Fig. 16) was subjected to a bi-directional input of 30 g, 11 ms. Figure 17(a) illustrates the acceleration response of the two events. As evident, the identical Tension/Compression performance of the single strut is here translated into identical reversal acceleration of the IMU platform, which is greatly desired for a Gyrocompass System. Figure 17(b) presents the Shaker and the IMU Travel and Sway along the Front-to-Back axis with the reversal IMU Sway results superimposed. The magnitude and phase match of the IMU Sway is almost ideal.

Fig. 15. MK27F System: 30 g Input Front-to-Back System Travel Overlay of Test and Predicted Data

Time (Seconds)

0.2



0.3

Test

0.4

0.5

Model

Fig. 16. MK27F Shock Isolated Test Setup IMU Platform





Sinusoidal Environmental Vibration

One essential design milestone of any shock isolation system is determining its resonance frequency, especially when supporting an IMU. A fine mesh of the IMU platform using solid elements was used to conduct a normal mode analysis. Linear spring and damping dashpot element were used to model the shock strut unit. The model Boundary Conditions restrained the IMU at the Base's mounting points. From the extracted lowest ten modes, the first three modes are indicative of the shock isolation system rigid body motion along each of the principal axes, with natural frequency of 6.0 Hz along X-Axis, 6.2 Hz along Y-Axis and 13.3 Hz in Z-Axis (Figure 18). Knowing the isolation frequency greatly enhances our understanding of the IMU behavior when subjected to floating shock platform shock test that has a selected resonance of 15 Hz. Here it should be noted that the first three modes are highly damped and come into play only when the shock isolation system's initial preload is exceeded. Therefore it is

expected that when the IMU platform is subjected to MIL-STD-167-1 input profile, the strut elements will act as rigid elements and only 1:1 transmissibility is expected without any significant gain at the isolated IMU level.

The higher frequency modes - namely Mode 4 through Mode 10 - show the isolated IMU platform's mass resonance above MIL-STD-167-1 forcing frequency range of 50 Hz. In Fig. 19, Modes 4, 5 and 6 are the first rotational modes about Y, X and Z-axes respectively, while Modes 7, 8 and 9 are the second rotational modes about Y, X and Z-axes. The tenth mode is the very first normal mode with pure flexural bending behavior of the Gearbox Cover. This is above the frequency range of 1 kHz as desired.

Considering the higher frequency resonance, the severity of the sinusoidal vibration input on the IMU platform was determined by subjecting the test article to a 1g amplitude sweep between the forcing frequencies of 5 Hz to 1000 Hz. This input was selected for two important reasons. Firstly, this input profile exceeds the Military and Commercial environmental specifications namely MIL-STD-167-1 and IEC-945. Secondly, it is in the dynamist's interest to quantify the resonant modes in each mutually orthogonal axis of input prior to the shock test.

Since this is a developmental effort for this new product, the IMU's dynamic performance under such input for the frequency range up to 100 Hz is indicative of overall MK27F System performance as an AHRS. As illustrated in Fig. 16, the measured acceleration of the isolated platform was monitored at the LN-200 IMU center of gravity. The test results shown in Fig. 20 along each excited axis of input clearly indicate that no resonance exist below 50 Hz (MIL-STD-167-1 highest forcing frequency). Between 50 and 100Hz, low Q (3.34) and highly damped resonance in the IMU platforms horizontal plane (mainly the Side-to-Side axis around 96 Hz) is evident, and this is well below maximum allowed gain of 5 (IEC-945). These findings



Fig. 18. IMU Platform Model First Three Translational Rigid Body Normal Modes

are advantageous to a gyrocompass's performance under a variety of external vibration inputs, since the isolation system remains rigid and unlocked.



Fig. 19. FEM MK27F IMU Normal Modes 4 through 10

Fig. 20. Mk27F IMU response at the Gearbox Cover to 1 g input of a sinusoidal vibration sweep between 5 Hz and 1000 Hz

A correlation is illustrated between the predicted results in Fig. 19 and the measured acceleration response given in Fig. 20. The discrepancy between the mathematical model Modes 4 and 5 with frequencies in the neighborhood of 88 Hz and that of the measured results at 68 Hz can be attributed to looseness in the actual IMU Assembly. From both the predicted and the test data it is concluded that there was no undesirable excitation of the coil spring or the strut assemblies. Finally, the recorded resonant frequencies will serve here as an indicator to set the low pass filtering (LPF) frequency of the Data Acquisition setup during the LWSM shock testing. Since all major resonances of the IMU platform occurred below 500 Hz, this will be the low pass filtering frequency of choice to process the collected data.

LWSM Test Results Summary

The IMU shock isolated platform test was conducted on a LWSM at Litton Marine Systems Test Facilities in Charlottesville, Virginia. The minimum available, one directional sway space inside the MK27F Enclosure for the IMU is 1.5 inches in the vertical direction and 1.7 inches in the horizontal direction. As required by MIL-S-901D, the IMU platform was subjected to a three blows with the hammer set at 1, 3 and 5 Ft drop height respectively. This was conducted in all three orthogonal axes of the test article. During these test series, it is imperative that both the

LN-200 IMU returns after each shock blow to its null calibrated position and that no sway space restriction is violated. It is also desired that the Shock Isolation System (SIS) attenuate the input transient is well below 90 g at the isolated IMU. The presented measured test data below consists of: 1). The measured acceleration of the input pulse and the attenuated response, 2). Overlay of IMU acceleration for 1, 3 and 5 Ft hammer height drop and last, 3). The isolated IMU mass travel history relative to the LWSM Anvil. The Front-to-Back test results are shown in Fig. 21 to Fig. 23. For the Side-to-Side axis refer to Fig. 24 to Fig. 26. Lastly, the Vertical test data are given in Fig. 27 to Fig. 29.

In summary the shock isolation system attenuates the LWSM MIL-S-901D blows to a maximum level of 52 g at the IMU level during the Front-to-Back 5' hammer height drop. The maximum sway is also well within the designed allowed clearances.



Fig. 22. LWSM Front-To-Back Axis for 1ft, 3ft & 5ft Hammer Height Drop IMU Response Acceleration



Fig. 21. LWSM Front-to-Back Axis 5 Ft Hammer Height Drop Input and IMU Response Acceleration Overlay



Fig. 23. LWSM Front-To-Back Axis for 1ft, 3ft & 5ft Hammer Height Drop IMU Peak-to-Peak Sway



Fig. 24. LWSM Side-to-Side Axis 5 Ft Hammer Height Drop Input and IMU Response Acceleration Overlay



Fig. 25. LWSM Side-to-Side Axis for 1ft, 3ft & 5ft Hammer Height Drop IMU Response





Floating Shock Platform (FSP) Simulation



Fig. 27. LWSM Vertical Axis 5 Ft Hammer Height Drop Input and IMU Response Acceleration Overlay



Fig. 28. LWSM Vertical Axis for 1ft, 3ft & 5ft Hammer Height Drop IMU Response



Fig. 29. LWSM Vertical Axis for 1ft, 3ft & 5ft Hammer Height Drop IMU Peak-to-Peak Sway

Since the floating shock platform (FSP) test is becoming the standard for all deck mounted equipment using isolators, the analytical model was subjected to the worst low deck frequency input environment found in the Taylor Devices database. This input, a 15 Hz deck frequency at a 20 feet standoff, was used at 100% in the vertical direction, and 50% in the horizontal plane.

Simulation results for the payload response accelerations are shown in fig. 30 for the three translational orthogonal directions, where Z is the direction of gravity, and X and Y are in the horizontal plane.

The horizontal input is in the X direction. This figure shows the vertical response approaching a damped resonance condition, where the X direction is rather benign after the first initial pulse. The maximum vertical response approaches 38 g's, well below the maximum survivable limit of this particular payload. Fig. 31 shows the system travel in each of the three orthogonal translational axes, with the maximum travel occurring in the soft X direction, even though 50% of the input is directed there.

Of interest here is that due to their orientation with respect to the input direction, some isolators offer more to the isolation system than others (larger strokes in some as shown in Fig. 32). It should be noted that an increase in the damping of approximately 80% was used in this simulation over that used in the previous 30g pulse and the LWSM test cases. The reason for the additional damping is to suppress the resonant like motion of the payload in the vertical direction, owing to the sustained 15 Hz input motion of the deck.



Fig. 30. Mk27F System: Predicted Payload Response on 15 Hz Deck, FSP Input



CONCLUSION

The replacement Gyrocompass, the MK27F, is a compact lightweight design, with added AHRS capability. This design maintained the same footprint, reduced volume and weight of its predecessor Gyrocompass with increased I/O capability and system performance. Utilizing new sensor technology, the LN-200, and COTS electronics, with eleven subassemblies come together to produce a Mil-Spec replacement system at minimum cost.

Analytical and experimental results were presented which demonstrate the effectiveness of the new MK27F miniature shock strut basic design for the different test platforms of MIL-STD-901D. The ability to satisfy MIL-S-901D 15 Hz Floating Shock Platform input were demonstrated through simulated results, by which the existing shock strut parameters were adjusted by increasing the damping by 80%, yet using the same coil spring element. A controlled test was devised and conducted on both the Single Strut Assembly as well as the IMU platform level using unidirectional input of 30g, 11ms half sine pulse. Single strut and IMU platform simulated responses to actual input pulses closely correlate to transient response in each case, be it strut stroke or IMU travel inside a confined space. Simulation results also correlated fairly well with recorded shock test data resulting in matching peak acceleration levels at the IMU. It is demonstrated that the use of in-line displacement and velocity Integrator by PCB, is adequate for shock transients, with results matching simulated levels as well as fixed-measurement. However, some of the discrepancies between the simulated and measured results are in large part due to data pickoff location and the actual path of motion. It is recommended that in future testing that the input and response of all

three orthogonal axes be included in all test orientations. These recommendations will be implemented during the First Article Test of a full-up MK27F AHRS scheduled to be conducted during 2002.

Although the basic shock isolated IMU platform design meets LWSM, it is demonstrated that this design has added buffer to meet MIL-S-901D for Heavy Weight Shock Machine HWSM/Floating Shock Platform (FSP). Where environmental vibration is a concern for Shipboard equipment, the MK27F Enclosure and the IMU platform structural dynamics integrity is demonstrated for inputs typical of MIL-STD-167-1 and IEC-945.

The difficult mechanical design constraints and challenging performance requirements of a low cost system can greatly increase development costs. Using vendor and interdivisional cooperation, mathematical modeling, and optimization testing, LMS has designed a robust, state of the art, minimum cost system ahead of schedule and under budget.

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