Ruggedization of the Gunner Display Unit for a Self Propelled Howitzer

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ABSTRACT

In this study, the experimental shock-vibration analysis and ruggedization of the gunner display unit (GDU) for a self propelled howitzer are performed. In the system, there is a fire control computer which includes high-speed processing and storage units together with a high-resolution color monitor that has to be resistant to harsh environmental conditions. Especially mechanical shock has the potential for producing adverse effects on the physical and functional integrity of all material. The effect of shock depends on the duration and magnitude of the response. In the analysis, shock and vibration control techniques using isolators have been studied to provide dynamic protection of the system units installed in the vehicles.

1.0 INTRODUCTION

ASELSAN Fire Control System for howitzers is designed to increase the fire power and first hit capability of the field artillery. The system with Gunner Display Unit (GDU) used in the system provides mission oriented and menu driven graphical user interface, which enables the user to perform the fire missions fast, accurately and effectively. In order to design GDU, an operational shock and vibration tests should be performed initially to obtain loading data from the main structure of the system at the predetermined location of GDU in the howitzer. Similarly, after designing and assembling the GDU, qualification tests are performed in order to monitor operational performance of the system. During the firing and vibration tests of the howitzer, integrated circuit piezoelectric (ICP) accelerometers are located at corresponding interested points for testing shock and vibration on the system. Shock Response Spectrum (SRS) analysis is performed to define the shock profile that the electronic equipments should withstand. It is also aimed to use required equivalent simple shock profiles during the shock qualification test of the equipment.

The aim of environmental tests is to ensure that production equipment meets the specified requirement over the full range of specified environmental conditions. Mechanical shock and vibration are the most complicated type of the environments, because of the importance of their spectral characteristics, but they must still be dealt with simple terms. Many vibration and shock specifications relate to conditions at the locations of use in that they provide design and development incentives for survival and operation of the product in such condition. Usually these specifications attempt to require the environmental tests to simulate such conditions. The specifications lead first to developmental tests that can guide the designers in revealing marginal features that might require redesign.

For many electronic systems, shock and vibration are a part of the qualification test requirements. Military and aerospace companies often must develop systems for use in severe life environments using Commercial-off-the-Shelf (COTS) boards or components [1, 2, and 3].

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Ruggedization of the systems are handled with reinforcement of the components that are located inside the equipments and/or external protection of the systems by isolators for minimizing disturbing force and/or modal design of the equipments and their mounting points. Initially, shock and vibration are caused by some types of sources such as tracks, motors of the vehicle, firing of a projectile etc. and these are unavoidable in the operation. In this case, the path of the energy which is transmitted to the target system should include isolators and/or should be modified according to the target sensitivities by optimizing stiffness and the mass of the structure.

Isolation of shock is the temporary storage of energy and its subsequent release in a different time relation. Typically, shock energy is imparted into the system; the mount deflects to absorb the energy, and releases it over a longer period of time as it returns to equilibrium. The acceleration input is characteristically a high acceleration level- short time duration pulse. The shock attenuation system can only respond at its natural frequency. If the isolators are selected properly, the time of energy release of the output will be very long compared to the time of the input [4].

Modal analysis is defined as the study of the dynamic characteristics of a mechanical structure. The modal parameters of all the modes, within the frequency range of interest, constitute a complete dynamic description of the structure. Much of the effort is expended in making mounting supports rigid and less is spent in damping them.

2.0 COTS EQUIPMENTS IN MECHANICAL STRUCTURES

The use of commercial off-the-shelf (COTS) hardware in military applications has led to uncertainty in its reliability performance and risk when operated in severe environments. The mismatch between the design and use environment is compounded by (a) a shift in predominant failure drivers experienced by COTS hardware versus its military equivalent in identical applications, (b) the effects of commercial practices on inherent reliability, (c) the ability to perform under the short- and long-term exposure to severe stresses, and (d) the cost of risk reduction options which may make a COTS equipment suitable for the application. The effects of COTS equipment reliability and risk on system operational readiness, sparing decisions, and maintenance and repair concepts must be considered in the logistics analysis. Assuming that COTS equipment reliability is good, without quantitative support, may invite potential disaster in critical military applications.

The approach included in this study to establish solution that account for between environments; identification of design risks; evaluation of field data to quantify the relationship between predicted and operating reliability [5].

2.1 Reliability Considerations for Mechanical Components

Recognition of reliability and maintability (R&M) as vital factors in the development, production, operation, and maintenance of today’s complex systems has placed greater emphasis on the application of design evaluation techniques. Many of the attempts to developed R&M prediction methodology have been at a system or subsystem level. The larger number of variables at these levels and lack of detailed knowledge regarding operating environment have created a problem in applying the results to the design being evaluated.

Attempts to collect failure data or develop an R&M prediction methodology at the system or subsystem level produce a wide dispersion of failure rates for apparently similar components because of the basic characteristics of mechanical components. The design evaluation procedures consider operating environment, critical failure modes and material properties at the part level to evaluate a design for R&M.

Therefore, the methodology for predicting R&M characteristics as part of this development effort does not rely solely on failure rate data.

Performance of a reliability prediction for electronic equipments is well established by R&D. For example, MIL-STD-756 and MIL-HDBK-217 have been developed for predicting the reliability of electronic equipment. Development of these documents was made possible because the standardization and mass production of electronic parts have permitted the creation of valid failure rate data banks for high population of electronic devices. Such extensive sources of quality and reliability information can be used directly to predict operational reliability while the electronic design is still on drawing board.

A commonly accepted method for predicting the reliability of mechanical equipment based on a data bank has not been possible because of the wide dispersion of failure rates which occur for apparently similar components. Failure rates of mechanical components are not usually described by a constant failure rate distribution because of wear, fatigue and other stress related failure mechanisms resulting in equipment degradation. Mechanical equipment reliability is more sensitive to loading, operating mode and utilization rate than electronic equipment reliability. Failure rate data based on operating time alone is usually inadequate for reliability prediction of mechanical equipment. Definition of failure for mechanical equipment depends upon its application. For example, failure due to excessive noise or leakage can not be universally established. Lack of such information in a failure rate data bank limits its usefulness.

The above deficiencies in a failure rate database result in problems in applying the failure rates to an actual design analysis. Estimating the design life of mechanical equipment is a difficult task for design engineers. Many life-limiting failure modes such as corrosion, erosion, creep, and fatigue operate on the component at the same time and have a synergistic effect on reliability. Also, the loading on the component may be static, cyclic, or dynamic at different points during the life cycle and the severity of loading may also be a variable. Material variability and the inability to establish effective database of historical operating conditions such as operating pressure, vibration, and temperature further compliance life estimates. The combination of these factors permit the use of engineering design parameters to determine the design life of the equipment in its intended operating environment, the rate and pattern of failures during the design life.

Predicting the reliability of mechanical equipment requires the consideration of its exposure to the environment and subjection to a wide range of stress levels such as impact loading [6].

In this study, both the Gunner Display Unit (GDU) that is taken into consideration and its mounting bracket are analyzed for designing and predicting reliability of the mechanical equipments for the howitzers.

3.0 SHOCK ANALYSIS OF THE HOWITZER FIRING

The howitzers are capable of carrying and firing conventional rounds. Many testing scenarios together with a maximum range of distance have been used in the firing tests (Figure 1). Especially mechanical shock has the potential for producing adverse effects on the physical and functional integrity of all material as well as GDU.

Shock is a rapid phenomenon that excites dynamic (resonant) response of the material but causes very little overall deflection. It is the term applied to a comparatively short time moderately high level force impulse input to material [7].

Mechanical shock is classified as a transient phenomenon where the equilibrium of a system is disrupted by a suddenly applied force or by a sudden change in the direction of magnitude or velocity unlike vibration which is classified as a steady state phenomenon. A shock input pulse is described by its peak amplitude A_o expressed in g's (gravitational acceleration), by its duration expressed in milliseconds and its overall shape which can take forms such as half sine, triangular, versed sine, rectangular and the form most likely to occur in nature, a more or less random shaped complex wave form [4,8]. Durations of shock that correspond with natural frequency periods of the material and/or periods of major frequency components in input shock environment waveforms that correspond with natural frequency periods of the material will magnify the adverse effects on the material's overall physical and functional integrity.

Figure 1: Firing of a self propelled howitzer.

Ballistic shock is also a special case of impart shock. Ballistic shock is the shock of impact of a projectile against a target. It may be measured as shock to the projectile or as shock to the target. Quite high energy levels are available in ballistic shocks. Artillery rounds impacting armor plate are a common form of ballistic shock.

Shock tests are performed to assure that subsystems can withstand relatively short duration transient vibration infrequently encountered during operations. Allowable firing shock limit can be specified using procedures described in MIL-STD-810F [7] which uses Shock Response Spectrum (SRS) to specify operational shock level. The response of a system to a shock can be expressed as the time-history of a parameter that describes the motion of the system [9].

3.1 Shock Response Spectrum Analysis

The Shock response spectrum value at a given undamped natural oscillator frequency, describes the maximum response of the mass of a damped single degree of freedom system (SDOF) at this frequency to a shock base input time history of duration.

The acceleration history due to a firing of the howitzer in any location is given Figure 2.

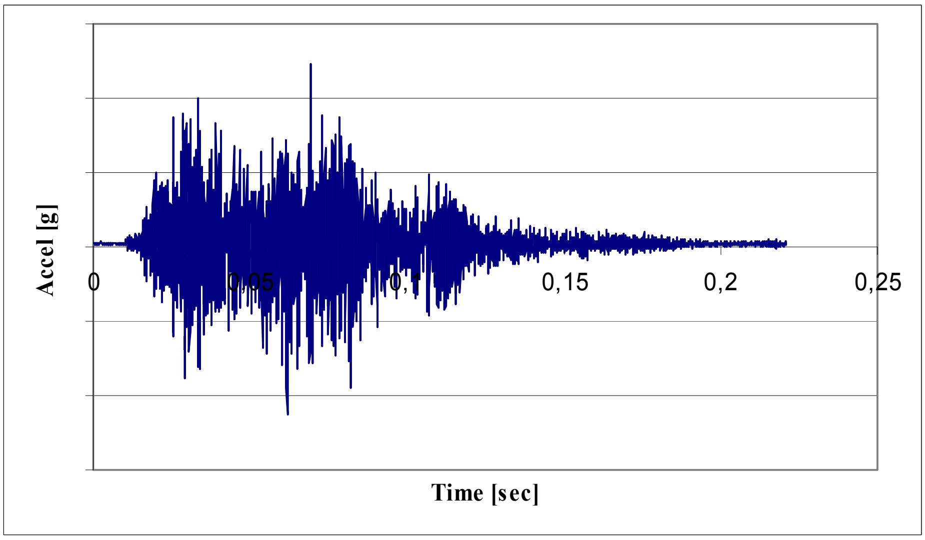


Figure 2: A shock time signal due to a firing of the howitzer.

The equivalent static acceleration is a steadily applied acceleration that is expressed as a multiple of the acceleration of gravity, which distorts the structure to the maximum distortion resulting from the action of the shock. The classical shock devices can produce several types of shock to simulate the field environment in laboratory conditions. These shock pulses are classified as saw-tooth wave form, half-sine wave form etc. The shock pulses should be fitted in SRS environment in order to achieve the same energy content of the shock time signal as seen in Figure 3.

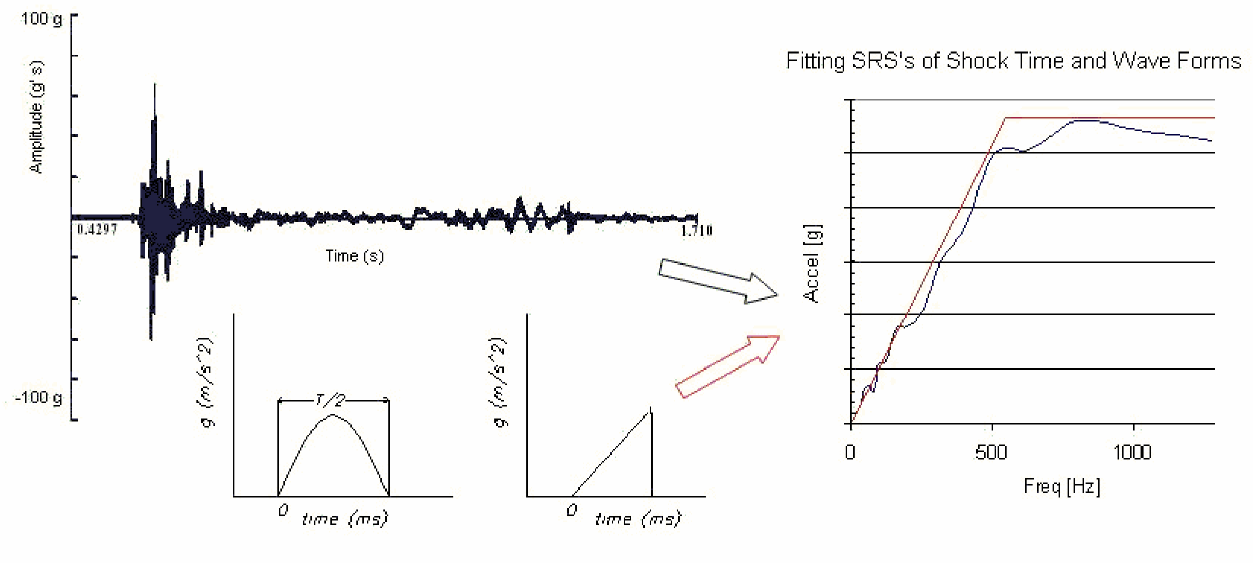


Figure 3: Simulation of shock time signal by fitting shock wave forms.

The SRS values of the GDU are prepared for drop shock table or electromagnetic excitation shaker by considering dynamic response of the structure.

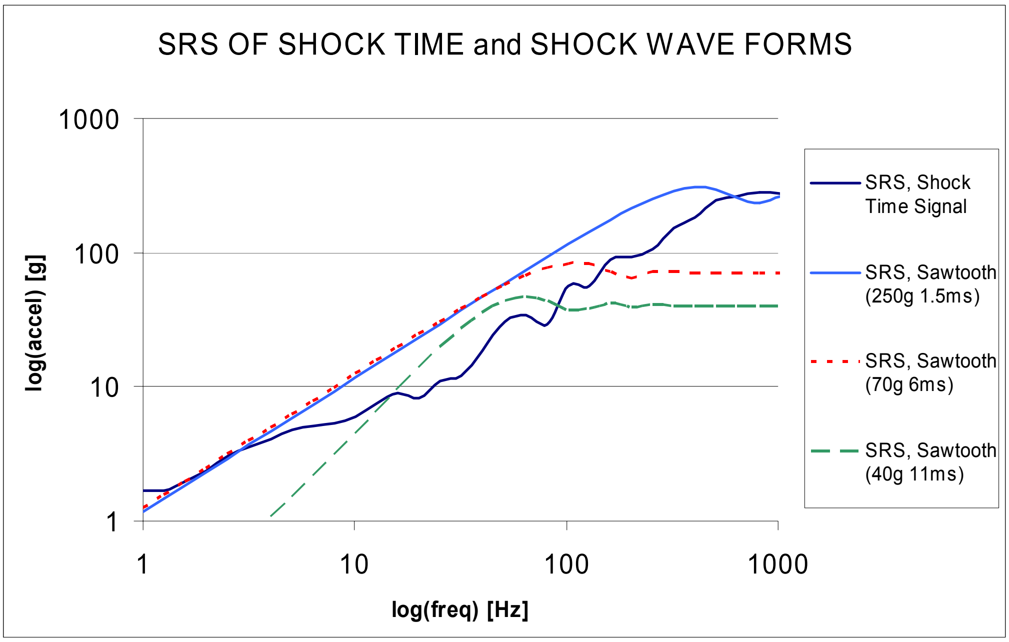


Figure 4: A Shock Response Spectrum signal for shock time signal [10].

4.0 THE SYSTEM ISOLATION AND THE MODAL DESIGN

4.1 Selection of the Isolator and Qualification Tests

The isolation system is the most practical defense against these damaging effects. Resiliently mounted equipment is protected from these forces in its environment, or conversely it is prevented from harming its own surroundings. Ideally, a passive isolation system requires no maintenance, takes little space, and keeps functioning under varying temperatures and in corrosive environments. It also should have the strength to restrain its load under catastrophic conditions and to return it to its normal operating position after the deflections caused by repeated shock loadings.

Shock and vibration so often occur together that an isolator must have two seemingly incompatible properties to counteract both forces effectively. These are:

1. Low natural frequency to isolate the relatively high frequency vibrations that lead to fatigue caused structural damage.

2. Ability to deflect in a controlled and repeatable way to absorb the impact loadings that would otherwise be transmitted into the isolated unit.

A non-linear isolator with a softening load profile and high damping meets these requirements as seen in Figure 5.

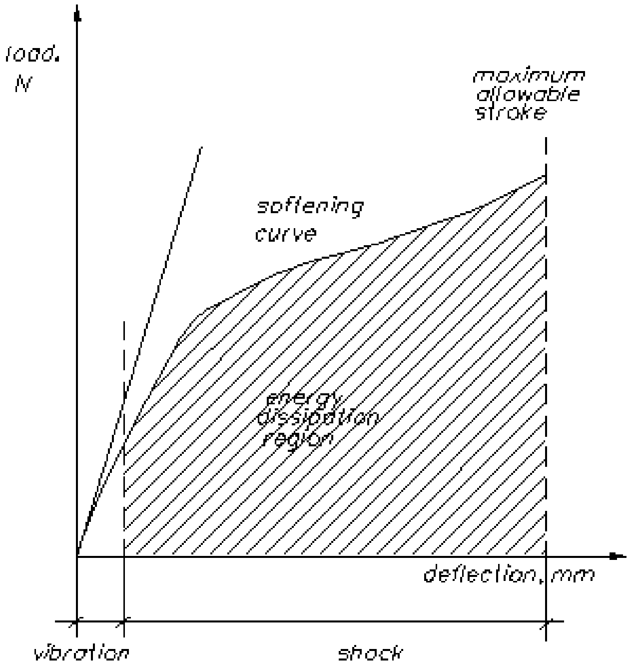


Figure 5: Load deflection curve of the isolator.

The isolating elements should make them unique in this respect. The load/deflection graph shows these two distinct regions of isolator performance.

Vibration control: In the vibration region, the isolator is relatively stiff. Its resonant frequency is represented by the slope of the curve at the static load being supported. As the amplitude of vibration increases, the mount becomes progressively softer shifting the resonant frequency away from the input ‘driving’ frequency and isolating the system.

Shock control: Further to the right in the graph, the non-linear isolator mount softens as the shock load is applied. As it deforms, it stores energy. The displacement reduces the acceleration level, through the controlled buckling of isolators (Figure 6).

A hardening isolator would stiffen rapidly as the shock load is applied. The isolator should have nearly uniform energy storage capacity over its entire deformation, keeping the maximum deceleration within acceptable limits. It is almost a constant force absorber over most of its stroke, regardless of how rapidly the load is applied. This characteristic means that its performance can be predicted and confirmed by actual results. The ability of the isolators to attenuate shock with minimum dynamic travel approaches the ideal curve shape. This provides a level of shock protection unavailable from any other isolating medium. It makes possible very compact mounting systems in shipping containers carrying sensitive loads, for vehicle-carried electronic instruments, and for many other installations where the equipment must be protected from dynamic forces inherent in its environment. Because shock may be much more severe than vibration, the isolator must have enough deflection capacity to store the shock energy without bottoming.

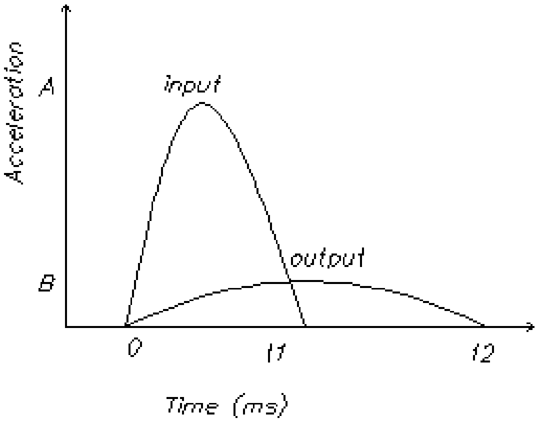


Figure 6: Illustration of shock isolation theory.

In practice, the non-linear response of a special isolator stores far more energy in the same travel or stroke than a linear device. The damping capacity of these isolators also dissipates energy. The mounting system rapidly decays the response oscillations produced by the initial shock, bringing the system to rest often before the next shock occurs. Fatigue damage is related to the number of cycles experienced by the equipment. Thus, keeping the number of oscillations and their peak amplitude to a minimum has a beneficial effect on the protected equipment. Selecting special isolators for shock applications involves some of the same considerations that influence their choice for service as vibration isolators [11, 12].

According to shock-vibration isolator selection the criteria, a suitable isolator is selected and tested in the laboratory with shock and vibration test machine in which SRS wave form and vibration profiles applied from the measured values of the specific locations (Figure 7). To simulate the firing shock in laboratory condition, drop shock table and/or electromagnetic excitation table method can be used.

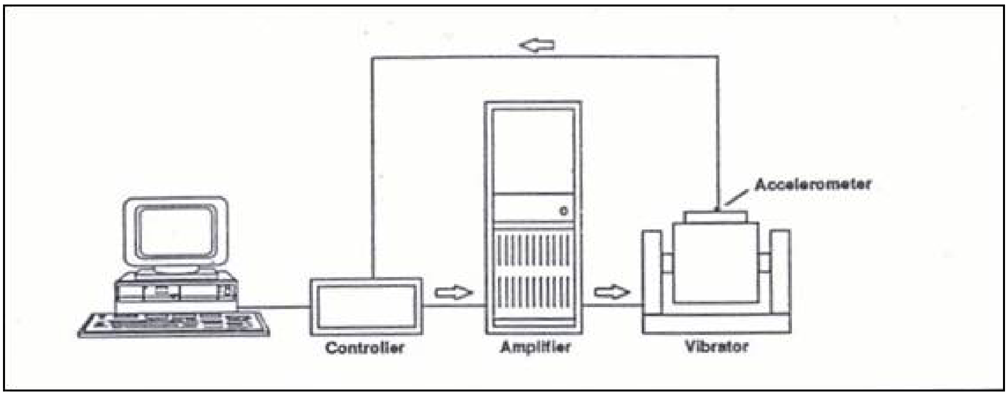
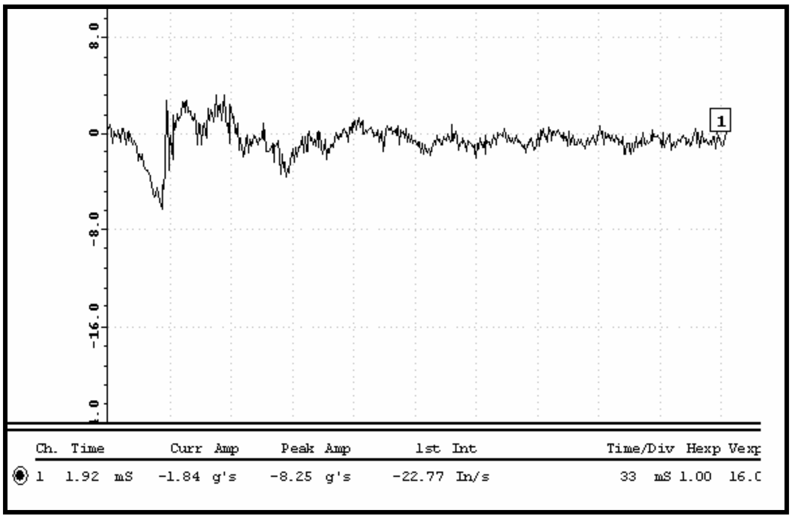


Figure 7: Shock and vibration qualification tests.

The isolation performance that has been tested with SRS form of the actual loading in the laboratory qualification tests is obtained satisfactorily (Figure 8). The isolation system protects the gunner display unit form the harsh operating environment of the howitzer for both shock and vibration.



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Ch. Time        Curr Amp      Peak Amp       1st Int               Time/Div Hexp Vex
● 1  1.92  mS   -1.84 g's    -8.25 g's     -22.77 In/s                33  mS 1.00  16.
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Figure 8: The resulting shock wave form after the isolation.

4.2 Modal Analysis of the GDU Supports

Modal Analysis of a structure determines its natural frequencies, normal-mode shapes and generalized parameters (mass, stiffness and damping) over a specified frequency bandwidth. These characteristics are fixed for a linear structure and can be considered as an “identity card” for use in complementary calculations (stress, fatigue, dynamic behavior prediction, performance, etc). Hence the modes of vibration represent the inherent dynamics properties of a free structure.

In this study, modal analysis performed in ANSYS [13] for GDU mounting bracket and it is intended to design the part (Figure 9) to be as rigid as possible over the frequency range important to the equipment respect to driving frequencies. The Finite Element Method (FEM) as being the most widely used method in structural dynamics studies brings the opportunity to predict the dynamic properties in the early design stages of any mechanical design.

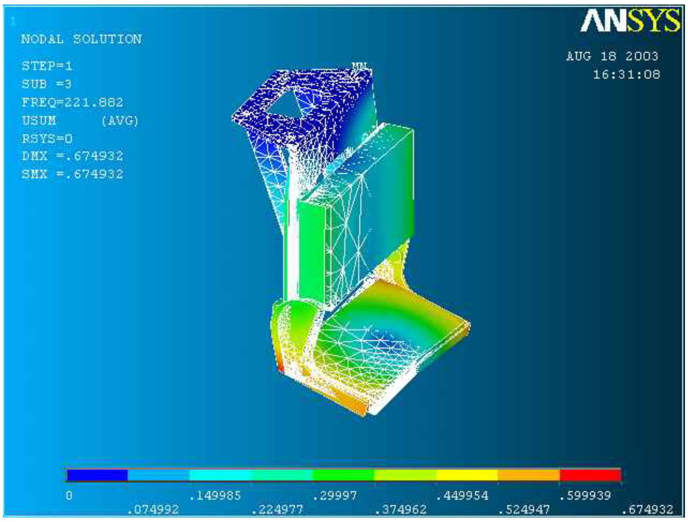

Figure 9: The modal analysis of GDU mounting support.

Since the professional FEM codes, like ANSYS, also have a vast amount of functionality and tools to model and understand the physical phenomenon for even large scale problems in a reasonable short time, the cost of development reduces drastically if one avoids the large modeling errors.

The GDU is tested in the operational field and qualified under harsh environments after all design requirements were completed.

Figure 10: The location of GDU in the howitzer.

5.0 CONCLUSIONS

Shock and vibration rank among the most destructive agents in the industrial society. They erode the life of mechanical and electronic equipment, driving it from service long before its time. Sometimes this premature deterioration stems from repeated overstress loadings, sometimes from fatigue failures of vital parts, and sometimes from a combination of both. Impact loading is clearly one of the most important and more complicated scenarios faced by engineers. Both the states of stress and the material strength parameters are influenced by elevated rates of loading.

Designs that use COTS products must take into consideration the harsh environments in which these commercial devices may be used. Some COTS suppliers offer hardware built to meet enough levels of heat, shock and vibration. Such ruggedized hardware may use commercial parts that are able to withstand extremes of shock, vibration, heat and humidity. Careful mechanical design of racks and chassis can help electronic subassemblies cope with shock and vibration requirements, while mechanical stiffening schemes provide increased vibration and shock tolerance. Designers need to make sure that frequency of mechanical resonance of a circuit board or component is not close to that of its housing.

As military vehicles continue to grow more complex, the importance of the use of integrated simulation and testing is even clearer. Improvements in simulation technology, including increase in computational capabilities and a better understanding of what constitutes a good simulation, have made this tool far more useful in supporting test programs. In addition, the new systems advanced designs (electronics-intensive and integrated systems) have driven the call for more extensive test programs.

The Gunner Display Unit is the part of ASELSAN Fire Control System that has been indigenously developed to meet howitzers requirements and it is ready to be tailored for the requirements of the other users in NATO, Partnership for Peace (PfP) and Allied Countries.

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