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Development of Shipboard Equipment Shock Survivability Assessment Technique (Continuation)

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DEVELOPMENT OF SHIPBOARD EQUIPMENT SHOCK SURVIVABILITY ASSESSMENT TECHNIQUE

EXECUTIVE SUMMARY

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Project Summary

Navy ships are expected to perform their mission in an arduous combat environment. Shock loading from non-contact explosions is one of many mechanisms that have the potential to cause extensive damage to these vessels. In particular, underwater explosions (UNDEX) resulting from mines, torpedoes, or other waterborne explosive devices pose considerable risk not only in structural failure, but also in terms of equipment damage, personnel casualties and ultimately mission kill. So critical is this issue that the Navy has outlined shock-hardening requirements for surface combatants in OPNAVINST 9072.2A. Per this instruction, the Naval Sea Systems Command (NAVSEA) established general guidelines for the verification, validation, and certification of surface ship shock hardness in the technical publication T9072-AF-PRO-010. While this document establishes a general method of shipboard equipment shock qualification, standardized criterion that delivers a survivable design, requires improvement to minimize existing uncertainty.

To this end, the initial effort of this study focused on assessment of the current technique so as to investigate uncertainties in the shock level response experienced during the shock qualification process as compared to the actual failure parameters. Using basic analytic approaches and finite element modeling and simulation, key parameters influencing the response and uncertainty in failure prediction were ascertained. The next effort focused on development of an improved guideline to enhance the survivability of shipboard equipment subjected to realistic UNDEX loading conditions. This was accomplished by developing unified criteria for functional failure of equipment, which were validated using computer modeling and simulation. These results generated a standardized procedure for the determination of shock-related failure in shipboard equipment. The suggested approach can be applied across various shipboard equipment and systems in the evaluation of shock hardness.

Keywords: *UNDEX, underwater explosion, FSST, shock hardening, equipment survivability*

Background

The purpose of the surface ship shock hardening program is to ensure that U.S. Navy combatants are capable of performing their mission whilst subjected to underwater explosion events. As design level live-fire testing is not practical for vessels of this type. the ship system, comprised of the ship structure, equipment and crew, must be tested in a representative manner in order to verify its performance under realistic UNDEX conditions.

Currently two main paths exist to provide shock qualification of shipboard equipment: a) incremental reduced level explosive testing and b) assessment by other means of verification.

Of these, some argue that live-fire testing is by all means the closest representation to the actual combat event, as it produces an explosive shock loading and thus must be mandated for shock verification. However, this is not necessarily the case. Typical live-fire testing options, which consist of the heavyweight or floating shock platform (FSP) shock test, as it is more commonly known, and the full ship shock trial (FSST), which is considered to be the gold standard of shock testing by some (though not even a qualification test), do not replicate design level shock loading, but are merely representative in nature. Thus, neither of these two approaches may actually result in the desired outcome, which is the accurate prediction of how a specific equipment or system, as installed within the ship, will perform, given a threat level shock loading condition.

The MIL-DTL-901-E, which provides the basis for shock qualification testing, offers additional options to vendors in order to demonstrate that their equipment is acceptable for shipboard use in a shock environment. Yet it lacks definitive criteria beyond simple categories of non-operational, visually damaged etc. that would lead to a "failure" rating. There is no quantitative performance rating for the equipment being tested in most cases, unless specifically called out as an additional requirement in the contract.

In order to drive out this type of uncertainly, an improved acceptance guideline is necessary. The objective of this project was to develop a new procedure for shock-hardened equipment.

Findings and Conclusions

What is ultimately desired is a means by which to link representative shock qualification testing of shipboard equipment to the actual response performance of the equipment in a realistic shock environment without having to place the ship in peril. Through the systematic analysis of recorded qualification test data, a more reliable assessment of shipboard equipment response can be achieved. By requiring the measurement of dynamic response parameters of equipment undergoing qualification testing through instrumentation accelerometers, strain gauges, etc.; a threshold value can be established. In the case of a successful test conducted in accordance with the MIL-DTL-901E, where the equipment continued to operate as required, the measured critical response values in this study are used for comparison with simplified equipment models exercised in a realistic full ship shock scenario via validated finite element modeling and simulation (M&S) techniques. By comparing equipment model response in the simulation against those measured from physical testing, using the newly developed unified criteria for functional failure, a conservative estimate of true shock survivability can be made. Furthermore, this bridging of measured and simulated response at the equipment level provides a means of focusing on potential equipment response in different loading conditions, placements and orientations than were realized through the limited physical testing.

The general procedures for implementation of the new approach as an update to the existing shock qualification standard are summarized here. In the case that a piece of equipment is to be shock qualified for shipboard installation and use, the following procedure is recommended.

1. Prepare equipment in accordance with MIL-DTL 901-E procedures for shock validation of shipboard equipment based on grade, class, weight, form factor, etc.
2. Apply accelerometers to test article, or velocity meter, if practical, to record base input motion to equipment scheduled for test.
3. Measure physical response (acceleration, velocity, strain) away from the base.
4. If the equipment passes current test requirements, proceed with the following. If it does not, modify, redesign and retest the equipment.
5. Create a reduced-order multi-degree of freedom (MDOF) equipment model via modal analysis (system identification procedure) using existing FEM model, if available.
6. Evaluate MDOF model in fully coupled ship shock FEM simulation using recorded 901 Series data (installed accelerometer, velocity meters, strain gauges as input, or desired shock scenarios is unavailable).
7. Place equipment at planned installation locations within the ship model, if known.
8. Extract acceleration, velocity and displacement response values from M&S.
9. Validate equipment against both the known failure limit (Physical result from current 901 Series test, ensuring visual pass) and the new failure criteria based on maximum velocity and change in displacement.

Recommendations for Further Research

The criteria developed for functional failure of shipboard equipment was validated using numerical modeling and simulation. For additional confirmation, a series of experimental tests are recommended in order to further validate these functional failure criteria.

Acronyms

Finite Element Method	FEM
Floating Shock Platform	FSP
Full Ship Shock Trial	FSST
Live Fire Test & Evaluation	LFT&E
Modeling and Simulation	M&S
Multi-degree of Freedom	MDOF
Naval Sea Systems Command	NAVSEA
Underwater Explosions	UNDEX