ANEP 63

Shock Mount Characterisation

NATO NAVAL ARMAMENTS GROUP

NG6/SG7 ON SHIP COMBAT SURVIVABILITY

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RECORD OF CHANGES

Issue	Date	Details of Changes
A	April 1999	First draft presented at Koblenz (Reference DERA/MSS/7X/C23.130)
B	July 2000	Including comments from US and NL, new document reference
1	January 2001	Minor editorial changes.

Section 1 - The Mount Characterisation Process

1. Introduction

1.1 This document addresses the characterisation of shock mounts for naval use and the presentation of the data in a standard format.

1.2 Section 1 covers, in broad terms, the need for mount characterisation, the methods available for characterisation and a procedure for the characterisation process.

1.3 Section 2 defines the format for the presentation of the mount data.

1.4 This document does not address the characterisation of mounts for noise reduction purposes. Where this information is required mount vibration data should be supplied in accordance with an appropriate national/international commercial standard.

1.5 The document has been produced by the NATO Naval Armaments Group NG6/SG7 on Ship Combat Survivability.

2. Background

2.1 When subjected to an attack from underwater weapon, the structure, systems and equipment of a warship can experience a severe loading. In general, it has been found that, unless specific measures are taken to either harden or protect the equipment, the equipment will sustain damage at attack severities well below the level survivable by the ships structure. To overcome this problem it was common for Navies to procure specially ruggedised equipment to meet their needs and to only use shock mounts when further hardening could not be achieved. However, in recent times, there has been growing pressure to reduce the cost of warship procurement. One of the favoured methods of achieving this cost reduction is to make greater use of less rugged equipment and/or COTS equipment and to protect the equipment using shock mounts.

2.2 The use of shock mounts however does not guarantee that the performance will be acceptable. Before the equipment can be used it is still necessary to check that the equipment will survive the transmitted motions and that the equipment installation (shock clearances and service connections) is adequate. Current design rules tend to be conservative either leading to the use of excessively rugged equipment and large shock clearances or requiring further (expensive) validation. Furthermore, these design rules could be invalidated if predicted changes in future warship structure such as novel hull forms are used and commercial construction methods adopted.

2.3 However using accurate mount characteristics in combination with a clearly defined structural input and a specified equipment ruggedness level, it should be possible to numerically model all equipment installations. This would allow the mount installation to be optimised to provide adequate shock protection whilst minimising the impact on the ship fit out requirements.

2.4 This document describes in broad terms the methods available for shock mount characterisation and defines a procedure and agreed format for the characterisation of shock mounts and the presentation of the mount performance data.

2.5 The agreement of a standard format for publishing the mount data will assist the NATO nations in both their own national equipment projects and in international collaborative equipment projects.

3. Intended Users

3.1 This document is intended for use by the following parties and for the following reasons.

3.1.1 Mount Suppliers - To inform them of the testing that should be performed before a mount is offered for naval service.

3.1.2 Equipment designers - to allow them to specify the pre-requisite information required before conducting a numerical assessment of a mounting system design.

4. Mount Design and Performance Overview

4.1 Mount Types

4.1.1 There are a large number of different types of shock mounts using different methods of shock attenuation available. Typical flexible mountings can be divided into three groups.

4.1.1.1 Resilient mountings: Mountings which absorb energy at a high rate and give out a large proportion of this energy at a low rate and may therefore be termed frequency changers. Typical examples are steel springs of various types, liquid springs, air springs and rubber mountings

4.1.1.2 Plastic or yielding mountings: Mountings which absorb energy at a fairly high rate and give out a small proportion of this energy at a lower rate. A considerable proportion of the absorbed energy is dissipated in distortion of the mounting. The mounting can only transmit to the mounted item a certain maximum force, i.e. the mounting yield force.

4.1.1.3 Combined mounts using the two mechanisms described above

4.2 Factors Effecting Performance

4.2.1 The performance of the mount will depend upon a number of different factors. The main controlling features are listed below.

4.2.2 Mount Dependent Factors

4.2.2.1 Mount geometry and design

4.2.2.2 Mount material

4.2.3 Application Dependent Factors

4.2.3.1 Mount preload and setup

4.2.3.2 Mount orientation

4.2.3.3 Temperature

4.2.3.4 Shock input, severity and orientation

4.2.3.5 Age

4.2.4 The mount characterisation process data should aim to address these factors.

5. Mount Characterisation Options

5.1 In many cases it will not be either physically possible or economically justifiable to fully characterise the shock mount to accommodate all the variables listed above. The objective of this standard is to ensure that the designer is provided with sufficient information to enable the validity of the mount model for a particular application to be assessed and an assessment of the magnitude of the likely errors that will result from the use of the model.

5.2 Since the level of complexity required in any mount model will depend upon the type of mount under consideration, the severity of shock expected and the importance of the equipment being protected, it is impossible to define an entirely prescriptive method of mount characterisation that should be used in all cases. The following paragraphs therefore discuss the methods available and the possible shortfalls associated using each method.

5.3 The level of modelling may be based on direct solution of the equations of motion of systems of limited degrees of freedom, numerical integration of the equations or may involve more complex numerical methods, based on the finite element method.

5.4 In the simplest method of modelling shock mounts simple linear spring models are used. This approach however, while it is simple, fast running and may be the only action immediately open to the designer, can lead to gross misrepresentation of the mounts behaviour .

5.5 Shock mounts, even under low severity loads, are non-linear devices. This will lead to either an under or overestimate of the shock displacement and a conversely over or underestimate of the equipment accelerations.

5.6 A linear elastic model without any energy dissipative mechanism will not predict the above mount response correctly. Because no energy is being taken out of the calculation large displacements and incorrect seating and equipment forces may be predicted. This conservatism will inevitably mean heavier seatings and equipment foundations and lead to an overly conservative declaration of shock clearance envelopes and sway space. This is not efficient.

5.7 The next level of modelling would be to consider the mount as a linear damped spring. While this improves on the elastic undamped spring the lack of non-linear stiffness characteristics still severely compromises this approach.

5.8 The bare minimum required for a meaningful simple analysis would be the analysis of a mount as a non-linear spring with added damping. This approach offers at least the potential to predict the initial peak responses from shock loadings. Often these peaks, usually in terms of maximum transmitted acceleration and maximum displacement excursion are the main information required for the equipment designer and installer.

5.9 The most complex level of approach, considered here introduces the force surface method. This extends the use of the non-linear spring with damping model with the inclusion of a non-linear relationship between relative velocity across the mount and velocity-dependent damping forces.

5.10 Yielding mounts may require a slightly different approach. In these cases the maximum transmitted force or acceleration to the mounted item can be assured to be no greater than the mount yield force and more sophisticated modelling may not be required.

5.11 Irrespective of the mount model used, the characterisation may be undertaken using either experimental or numerical methods. Providing the resulting model is correctly validated either approach is deemed acceptable. The important feature being that outputed mount model can be fed into the appropriate equipment / system model allowing it to operate using the minimum level of computer resources. It would be undesirable for a sizeable proportion of the cpu time required to run the model to be used determining mount performance.

5.12 Although this document concentrates on experimentally derived characteristics, the format for presenting the data in part 2 is also to be applied to numerically derived characteristics.

6. The Force Surface

6.1 Introduction

6.1.1 The force surface method has been selected as the preferred method of presenting the mount data since it will also enable the presentation of mount characteristics based on the simpler models as discussed above.

6.1.2 The force surface method is a technique which extends the use of non-linear force-deflection relationships to include velocity dependent forces. The technique uses the fact that relationships between measured mount restoring force and the dynamic variability of the mount displacement and velocity response can be measured, and their inter-relationship quantified. The force surface therefore essentially relates mount restoring force to relative displacement and relative velocity across the mount. Once established, this surface will not only reflect the non-linear nature of the static force-deflection characteristics of the mount but also the influence of the non-linear, velocity-dependant, dissipative forces.

6.1.3 Irrespective of the character of the loading, the force surface describes how the mount will respond. The mount, responding as a dynamic system is constrained to move on the surface and unless the mount bottoms or there is significant plastic deformation the interrelation of displacement, velocity and force should always conform to it.

6.1.4 The only limitation to this method is when it is used for a mount that yields or is damaged as a result of the shot. In this case, the mount will jump to an essentially parallel surface offset by the change in displacement cause by the yielding.

6.2 Mount Characterisation Measurement Strategy

6.2.1 The first stage in generating the force surface for any particular mount condition is to gather as much data as is practically possible extending over the full operating range (displacement and velocity) of the mount.

6.2.2 In order to provide ordered data to describe a surface, the preferred method of constructing this surface would be to acquire the force-deflection characteristics at a constant velocity, and for a range of velocities. In practice however, the task of maintaining a constant value of velocity across the mount is virtually impossible, particularly when we require the characteristics of the mount when subjected to high severity, transient loadings. Under typical UNDEX loadings peak relative velocities across the mount are of the order tens of metres per second. Maintaining velocities of this magnitude, even for a short period of time is not feasible. It is far simpler to allow the displacement and relative velocity to vary in a non-constant manner and effectively gather a collection of non-ordered data points to describe the surface.

6.2.3 For the smaller mounts the force surface data collection can be achieved by applying a variable severity mechanical shock to the base of a four mount rig on a shock test machine. For larger mounts it will be necessary to use either a single mount rig with guides on the shock machine or generate the input, to multiple mount rigs, explosively on floating platforms. During the testing above and below mount displacement transducers are to be used to record the relative motion across the mount.

6.3 Derivation of the Force Surface

6.3.1 Following measurement of dynamic mount displacement response, a simple subtraction of the measured above and below mount displacement provides relative displacement (x) across the mount and differentiation once and then twice with respect to time gives the relative velocity (v) and acceleration respectively. And finally, mass factoring the absolute acceleration as measured on the mass gives the force (F) across the mount. At this stage the data can be viewed in standard force-deflection and force velocity relationships. An example of the velocity displacement curve for a typical test is shown in Figure 1. By considering instantaneous values of x, v and F, points are established on the force surface.

6.3.2 The results from multiple shots can then be combined to increase the data population on the force surface. The final process then involved the interpolation of the data enabling a matrix of force deflection values at constant velocity to be calculated. Figure 2.

7. Instrumentation Considerations

7.1 The choice of instrumentation for characterisation data collection is enormous. Non-contact displacement transducers have been used, measuring displacement directly with respect to the fixed laboratory frame. Contact displacement transducers have been used also since the activation force for these devices is typically orders of magnitude less than those of the mount restoring forces. Therefore while they are acting as a contact device they can be described as non-invasive. They are however intolerant of rotations, are not particularly reliable under shock loadings and are stroke limited.

7.2 Seismic velocity meters above the mount system are not suitable and provide no useful information due the close proximity of the seismic frequency of the velocity meter to the fundamental response of a low frequency mount. Subsequent correction of the seismic coloration of the validation data removes the majority of the fundamental mount response also. Relative velocity meters can provide useful results but again are not tolerant of large rotations and in some instances the stroke may not be sufficient. The large UNDEX coil-magnet combinations used as robust transducers in the UNDEX field are stroke limited to 50mm. For smaller meters used for scale model tests this is reduced to 25mm. Care must be taken to ensure that this stroke is sufficient to accommodate the maximum anticipated mount deflections. Laser velocity meters are now the preferred instrumentation.

7.3 Accelerometers have their uses in determining the force surface characteristics, however caution must be exercised if they are used to determine the below-mount base input information required to calculate the relative force surface. Accelerometers used under shock are unreliable due to stress wave coloration of the signal and potential for the high frequency content of the UNDEX shock input to permanently polarise the piezo elements. Their main use in this work is in the measurement of above mount response where in most circumstance the mount being characterised acts as a suitable mechanical filter reducing the technical problems which are experienced measuring below mount responses. Accelerometer technology is however steadily improving and the problems can be overcome with the correct choice and application of accelerometer.

7.4 Passive detection techniques are also recommended to determine whether a mount under test has “bottomed out” during the characterisation tests. It may not be immediately obvious from measured dynamic responses that bottoming has occurred particularly if the instrumentation is severely limited in the high frequency range. Through most of the characterisation tests it has been considered prudent to include measures to detect bottoming other than by inspection of data. These include high speed video surveillance of the mount specimens, close inspection of mount bolt heads for evidence of collision and the use of a witness material between the closest point of the above and below mount structure to confirm whether collision has occurred.

8. Transposition of force surfaces

8.1 There are a number of factors relating to the installation environment that will effect the performance of the shock mount. These factors include the mount preload, mount/snubber setup, mount age, mount condition, the ambient temperature etc. Whilst it would be theoretically possible to characterise the mounts over a wide range of conditions it will never be practical to do so. Guidance will therefore have to be given on how to interpolating and extrapolating the data to cover the full range of normal operating conditions.

8.2 A further complication is that shock mounts are often supplied as a range of geometrically similar mounts covering a significant mass range. (The type X mount is available in 8 standard sizes) the similarities between these mounts mean that it is possible to extrapolate performance data between mount sizes.

8.3 Guidance will therefore have to be given on how to interpolate and extrapolate the data to cover the full range of normal operating conditions. Where applicable a suitable audit trail should also be provided to show exactly how the mount performance data was derived so that the designer is fully aware of the degree of data manipulation that has been undertaken.

9. Validation Of Mount Data

9.1 Since the mount data is likely to be used in numerical models by equipment designers where it may be impossible to validate the full model, it is essential that the process of validation is carried out as part of the characterisation process. Ideally, this should take the form of predicting the response of a shock test conducted against the mount under a different preload and input condition to that used for the characterisation. Cost constraints may however prevent this from being done in which case one of the actual characterisation tests should be modelled. In addition to the dynamic modelling, the static force deflection curve for the mount extracted from the force surface should be compared with the measured force deflection curve for the mount.

9.2 In general the variation between the measured and predicted force and displacement should be less that 20%. This value can however be varied at the discretion of the acceptance authority.

10. Implementation of the force surface as a predictive tool

10.1 An advantage in characterising mounts in this manner is that the force surface data can be readily adapted for input into proprietary finite element packages. A functional description or look up table of values for the mount surface can be easily incorporated in most finite element codes by the production of user written elements.

10.2 A user written element can be defined which essentially provides a link between two node points of a given finite element model to represent a mount with non-linear dynamic characteristics. It is unidirectional and is based on the interrogation of a force surface-based database, supplied by the modeller in matrix form or via the user-written subroutine method.

10.3 An element set up in such a way would determine the relative displacement from equilibrium across the mount dimension by reference to the previous solution step in the finite element calculation, the relative velocity across the mount is also referenced in a similar way. With these values the four nearest known data points on the force surface are accessed from the supplied matrix and by a process of bi-cubic spline fitting the actual force for the given relative displacement and velocity is obtained. In addition the surface also yields the damping coefficient of the mount in that dynamical state by differentiation of the surface with respect to relative velocity given that displacement is held constant. Similarly the dynamic stiffness of the mount is provided by the derivative of force with respect to relative displacement given a constant relative velocity across the mount. The mount restoring force value, damping value and dynamic stiffness are then passed back to the main finite element program.

Figure 1 – Mount Velocity/Displacement Curve

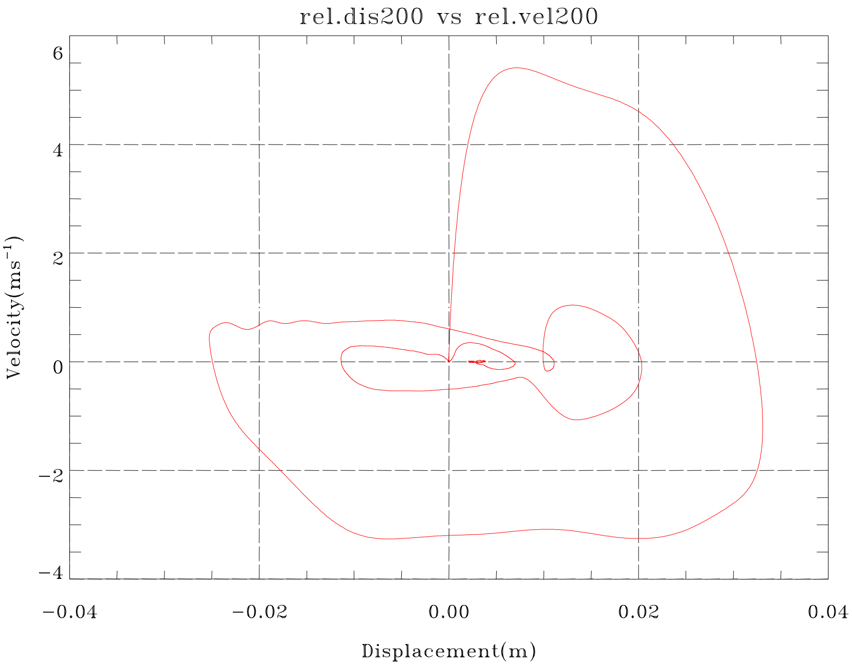
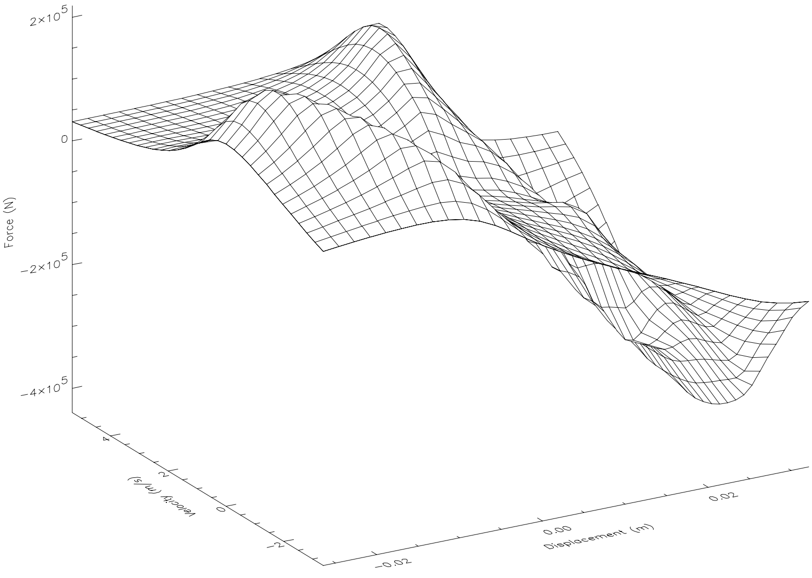


Figure 2 – Mount Force Surface



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Section 2 – Mount Data Template

1. Background

1.1 The purpose of this section of the document is to define the format for the physical and performance data on a standard range of mount types and associated components.

1.2 The aim is that each mount description is to be sufficient to identify its suitability, or otherwise, for any particular application and, if suitable, to provide all of the necessary information and data for the mounting system design, the mount installation and inspection.

2. Presentation of the Mount Data

2.1 The presentation of the mount data is to be structured to enable each mount (or mount type if appropriate) to be contained in a "stand alone" data sheet that could be subsequently combined into either national or a NATO catalogue of standard mount types.

2.2 Each mount "data sheet" is to have the following contents:-

Section 1 Nature and Application of the Mount

1. Generic Type
2. Application
3. Load Range
4. Shock Displacement
5. Environmental Constraints
6. Frequency Range (if know)

This section is to contain sufficient general guidance on the nature and properties of the subject mount so that the mounting system designer can decide whether, or not, it offers any prospect of meeting this particular requirements.

Section 2 Description of Mount Assembly

1. Complete Assembly
2. Mount
3. Associated components

This section is to give a detailed description of the mount and associated components and is to include drawings of the mount and associated components along with a description of how the mount works.

Section 3 Mount Standard Assembly and Installation

1. Standard Assembly
2. Installation

This section defines the standard assembly of the mount e.g.-types of fixtures and fittings, how the mount is to be assembled, orientation of the mount, shock clearances around the mount, support structure stiffness. The text in the section is to be supplemented by figures as appropriate.

Section 4 Size, Mass, Data and Dimensions

This section is to expand upon the physical data given in section 1 and is to define in more detail the size and mass range for each mount (and associated components) in the range under consideration.

Section 5 Performance Data

1. Performance summary
2. Force surface

The performance summary details are to give the headline performance characteristics of the mount responding to a “typical” input shock (details of the input shock are to also to be defined). The data should be tabulated as shown in Table 1. The aim of providing the data in this form is to enable a relative easy comparison of the mount performance to be made to determine whether it has the potential to offer the protection needed. The actual performance can only be reliably estimated by the use of the force surface data, or equivalent functional form of the force-displacement-velocity algorithm. If the mount dynamic characteristics are described as force surface data then this data is to be provided in a suitable electronic format and is to consist of data stripes of force/displacement at constant velocity. Otherwise, the functional form of the best fit governing equation will be provided along with the corresponding coefficients.

The data sheet should define fully the mount setup conditions for each force surface or best fit governing equation provided and define a procedure and limits for transposing the data to different conditions.

It is recommended that the data sheet also contains a plot of the force surface (from either the tabulated data or best fit governing equation) and of the static load defection curve.

Mount Size No				**1**
Nominal Load			kg	10
Static Stiffness		Vertical V	N/m	
		Horiz. H_A		
		Horiz. H_R		
Dynamic Stiffness		Vertical V	N/m	
		Horiz. H_A		
		Horiz. H_R		
% Of critical Damping				
Vertical Static Displacement at Nominal Load			mm	
Natural	Vertical V	Nominal Load	Hz	
Frequencies	Horiz. H_A	Nominal Load	Hz	
for Vibration	Horiz. H_R	Nominal Load	Hz	
Dynamic Magnifier at Resonance		Nominal Load	-	
Shock Displacement		Vertical V	mm	
Capacity		Horiz. H_A		
		Horiz. H_R		
Maximum Transmitted		Vertical V	m/s^2	
Acceleration at Nominal		Horiz. H_A		
Load		Horiz. H_R		
Range of validity of Mount Surface/Best Fit governing equation (where applicable) relative to unloaded condition			± mm	
Required Support Stiffness			N/m	
Required Support Strength			N	

Table 1 – Mount Performance Summary Data

Section 6 Mount Characterisation Process

1. Method of force generation – i.e. Shock test machine or barge
2. Number of mounts used/shots fired
3. Mount supplier (if appropriate)
4. Degree of extrapolation/interpolation
5. Validation checks carried out
6. Documented mount permanent deformation
7. Name of test house used for characterisation
8. Date of testing

This section is to provide the audit trail for the characterisation data.

Section 7 Protection, Inspection and Maintenance

This section is to identify any mount specific protection, installation, inspection and or maintenance requirements.

Section 8 Procurement Information

This section is to contain sufficient information to allow the mount to be easily sourced and is likely to contain details of stock numbers, manufacturing specifications, drawing numbers, approved suppliers etc.

Section 9 Historic Information

This section can be used to explain any changes in the mount details over time resulting from (for instance) the adoption of metric material specs or a change of material from natural to synthetic rubber etc.