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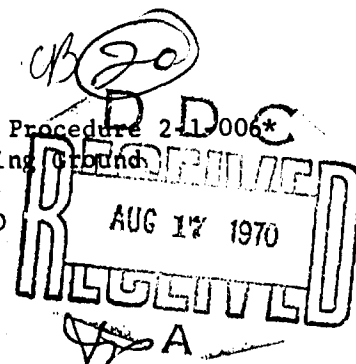
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19 May 1970

Materiel Test Procedure 2-1006\*  
Aberdeen Proving Ground

U. S. ARMY TEST AND EVALUATION COMMAND  
BACKGROUND DOCUMENT

MECHANICAL SHOCK



1. INTRODUCTION

The objective of this test procedure is to provide the test director with the general principles governing the measurement of mechanical shock.

Mechanical shock is defined as a nonperiodic excitation of a system characterized by suddenness and severity, and generally results in significant displacement in the system. Weapon firing, projectile impact on targets, and bottoming of vehicles are typical shock phenomena. Shock is present in almost all proving ground tests. It is measured primarily in connection with parametric studies or diagnostic tests.

Shock affects mechanical systems in two ways. The first and least prevalent manifestation is catastrophic breakage caused by the sudden application of massive forces that exceed the strength of the material in the system. The second and more prevalent type of shock-induced failure is shock-induced vibration in the system or system components. This vibration causes fatigue failure or loosening of fastenings or bonds.

The effect of shock in a system can best be analyzed by examining the wave shape of the shock excitation and comparing it to the system or component shock response. Comparisons are difficult in the time domain but quite simple in the frequency domain. The latter consideration dictates that shock data be presented in two forms, oscillograms in the time domain and spectral plots in the frequency domain.

Mechanical shock is generally portrayed as a time history of displacement, velocity, or acceleration, with the data obtained by means of oscillography and magnetic tape recordings. Since velocity and acceleration are successive time derivatives of displacement, a simple mathematical transformation provides the means of computing one from the other.

This materiel test procedure covers the means of displaying and reducing the data obtained from measurements of mechanical shock. The actual means of imposing shock, and the materiel involved, are covered by other MTP's.

2. MEASUREMENT OF SHOCK

2.1 GENERAL CONSIDERATIONS

In considering problems of mechanical shock, excitation is defined as the force or stimulus applied to a system, and response is defined as the motion resulting from the excitation. Since the same techniques and instrumentation are used to measure response and excitation, care must be exercised to

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differentiate between the two. The transmissibility of shock through a system is often a function of the characteristics of the system; i.e., types of material, spring constants, etc. As a result, unless great care is taken, response is measured rather than excitation. Excitation is best measured by carefully mounting the shock transducer as rigidly as possible to a point mechanically identical insofar as motion is concerned to the source of the shock. The structure between the shock transducer and the source of the shock will distort the shock record if its transmissibility is frequency dependent. The measurement of shock excitation is generally of little interest in itself. Response is usually of interest since this is the manifestation of shock that reveals the system's capability of withstanding the shock. Since response cannot be analyzed properly without excitation data, both should be measured if possible.

## 2.2 INSTRUMENTATION

The transducers used to measure shock must have sufficiently high frequency response to preclude frequency discrimination in the shock phenomena being measured. The transducers generally used are piezoelectric type accelerometers. These have the desired high frequency response characteristic, high signal output levels, and are small and easily mounted. Other transducers may be used depending on the nature of the test; among these are strain gages, strain resistance accelerometers, displacement gages, and velocity pickups. Oscillographic and/or magnetic tape recorders are used as the primary recording media. The use of magnetic tape recording is essential to subsequent data processing economy. The oscillographic recorder provides a visual time history of the phenomena which should be examined between trials to be sure of clear records. Tests should be stopped immediately if "noisy" records or other manifestations of instrumentation troubles appear. Data analysis and interpretation are impossible unless virtually perfect records are obtained.

The exact location of the transducers, the conditions of imposing shock, and the materiel involved will be determined from the appropriate QMR, test directive and appropriate MTP's which include: MTP 2-2-620, MTP 2-2-625 and MTP 2-2-808.

## 3. TEST DATA AND DATA REDUCTION

### 3.1 TEST DATA

The minimal data presentation is the oscillographic record of the shock. This record should have clearly delineated time and amplitude scales to permit determination of these values. An example of an oscillographic record is shown in Figure 1. This presentation in time domain does not always lend itself to subsequent analysis. The presentation of the data in the frequency domain is highly desirable. This is possible by using the Fourier integral:

$$F(\omega) = \int_{-\infty}^{+\infty} f(t) e^{-j\omega t} dt$$

where

$f(t)$  = time history of displacement, velocity, or acceleration

$$\omega = 2\pi f$$

$f$  = frequency

$F(\omega)$  = Fourier spectrum

$$j = \sqrt{-1}$$

$t$  = time

$F(\omega)$  represents the shock pulse in the frequency domain. The data presentation for shock is complete if, for each shock trial, a plot in the time domain (oscillogram) and plot of the amplitude of  $F(\omega)$  are presented, ideally, the plot of  $F(\omega)$  should include the phase angle.

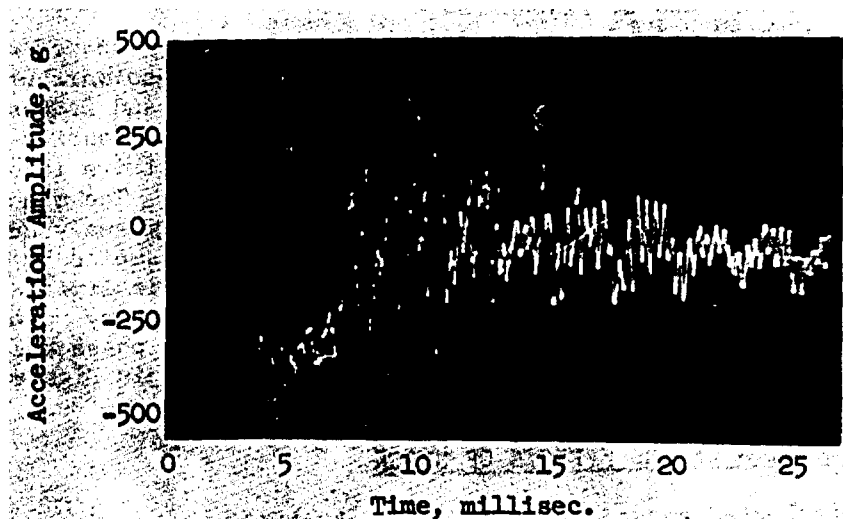


Figure 1: Oscillographic Record of a Shock Pulse.

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### 3.2 DATA REDUCTION

The primary problem in data reduction is in obtaining  $F(\omega)$  from  $(t)$ . The following procedures are applicable:

a. When the shock pulse is relatively long and the harmonic content primarily of low frequencies, an analog computer can be used to compute the spectral plots. This procedure is limited by the frequency response of the analog computers, usually less than 1000 Hertz. Improvement in frequency response can be realized by recording the shock on magnetic tape and "playing" the recording at lower speed in the analog computer. In any event, this means of reducing the data limits the maximum frequency of the spectral plot.

b. A second method of reducing data consists of first digitizing the shock pulse and then solving the equation in paragraph 3.1, above, by numerical integration for the spectrum. This procedure is tedious and time consuming unless a high-speed computer and electronic digitizing equipment are available. The upper limit of the spectral plot is limited, in this case, to the digitizing rate. Once again this limit can be increased by "playing" the tape into the digitizer at reduced speed. The application of this technique to the shock pulse shown in Figure 1 results in the amplitude and phase angle plots of  $F(\omega)$ , as shown in Figures 2 and 3, respectively.

c. A third method of data reduction provides a means of approximating the spectrum. The approximation is sufficiently accurate to warrant its use in most cases. This method makes use of a spectrum analyzer and is based on a comparison of the Fourier series and Fourier integral. The Fourier series approaches the Fourier integral as the period of the repetitive interval of the fundamental of the Fourier series approaches infinity. The magnetic tape record must be formed into a loop for use with the spectrum analyzer. The loop length should be infinitely long compared to the length occupied by the shock record. The actual ratio of loop length to record length is limited by practical consideration; a ratio of 50 to 100 produces satisfactory records. Such a technique does not lend itself to the calculation of the phase angle of  $F(\omega)$ . The application of this technique to the shock pulse shown in Figure 1 results in the amplitude plot of  $F(\omega)$  shown in Figure 4.

## 4. EVALUATION OF THE EFFECTS OF SHOCK

As indicated above, tests in which shock is measured are primarily limited to parametric or diagnostic studies. The particular test purpose determines how the data are to be analyzed. The following discussion provide examples of specific types of analysis.

### 4.1 PARAMETRIC STUDIES

Proving ground shock tests are used to determine the shock environment existent in or on military equipment. The measured shock environments can thus be used to devise a laboratory test. The laboratory test is then used to determine the ability of equipment to survive in the shock environment. As an example, consider the shock environment that fire control equipment must survive in the turret of a tank. The proving ground test would consist of mounting transducers in the turret of a tank in positions normally occupied by fire con-

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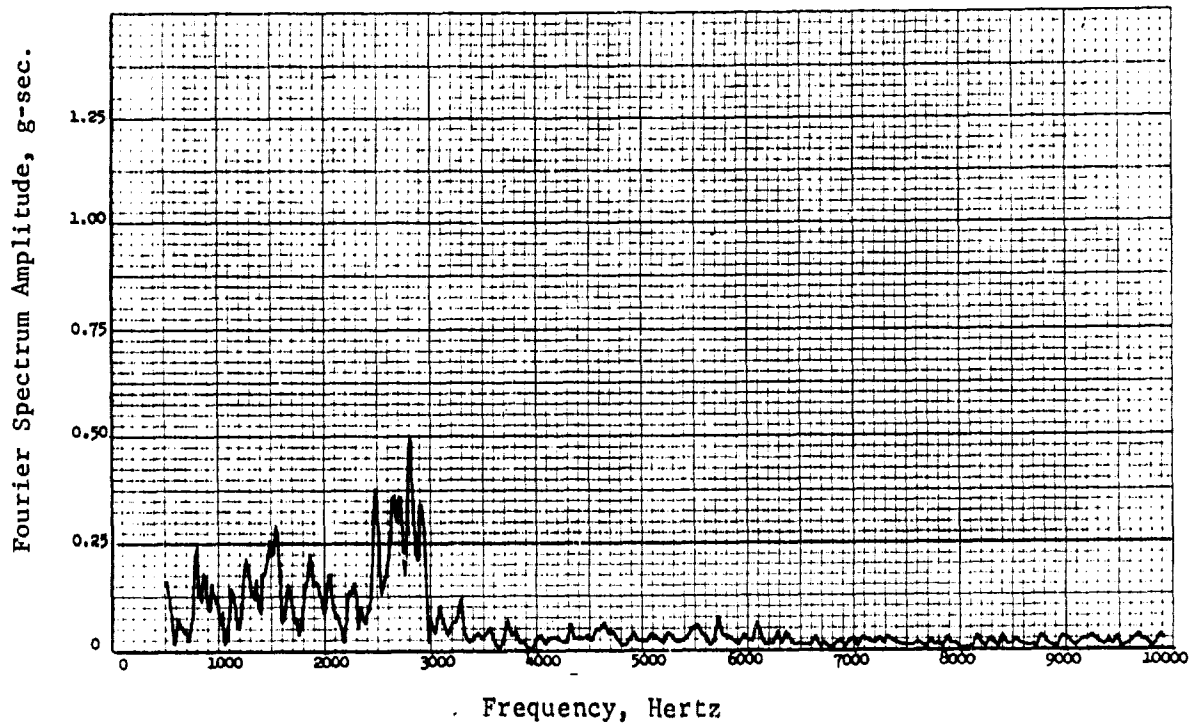
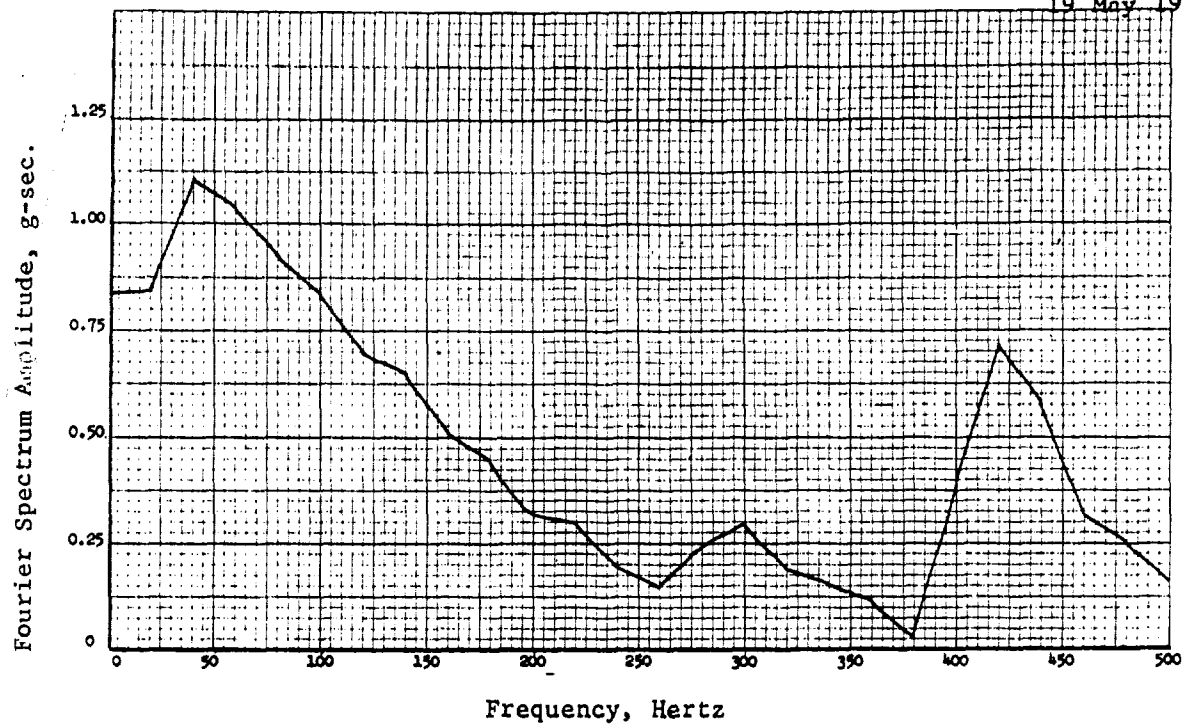


Figure 2: Fourier Spectrum Amplitude Analysis of a Shock Pulse  
Using a Digital Computer

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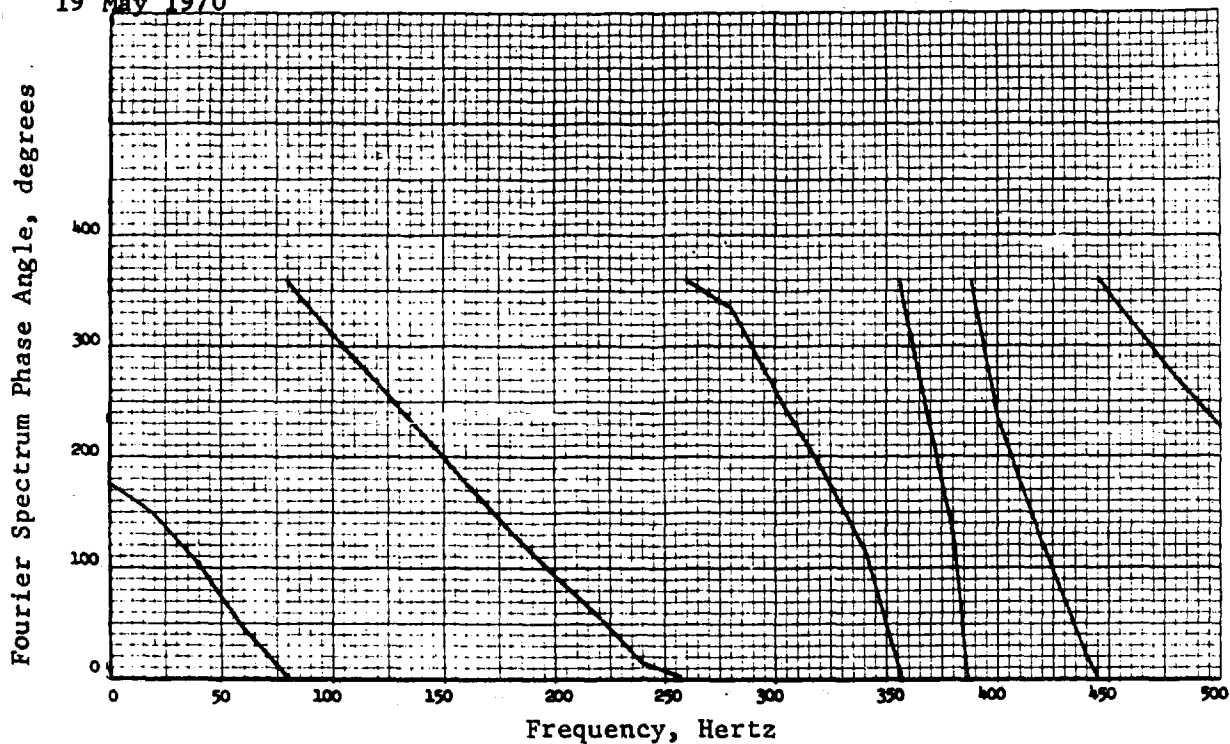


Figure 3: Fourier Spectrum Phase Angle Analysis of a Shock Pulse Using a Digital Computer.

trol equipment. The shock response of the turret to a nonpenetrating round, as described in MTP 2-2-602, would then be recorded. The shock response of the turret is the shock excitation to the fire control equipment. The Fourier response  $R(\omega)$  is first computed. Specific fire control equipment is examined and a band of frequencies selected. This band is chosen to encompass all of the principal damped resonant frequencies of the fire control equipment. Shock spectra available in Reference D (pp. 596-602) are compared to those obtained from the test results. A shock pulse shape is selected that most closely approximates that available in shock test machines with primary emphasis being placed in the selected frequency band. This, then becomes the basis for laboratory simulation of the tank turret environment on fire control equipment.

#### 4.2 DIAGNOSTIC STUDIES

In diagnostic tests the analysis of the data is primarily one of comparing the Fourier spectra of the excitation and response. The frequencies that appear predominantly in the response are those of the excitation and the damped natural frequencies of the structure. The coincidence of maxima or near maxima in the excitation spectrum with one or more of the damped natural frequencies of the structure is undesirable. This condition causes maximum response in the structure and can lead to early fatigue failures or erratic operation of mechanisms. It is determined readily by direct comparison of the excitation and response spectra or by plotting the ratio of response to excitation against frequency. Although this direct comparison neglects the phase angle associated with Fourier spectral analysis, it is possible that when the ratio exceeds one, an unfavorable situation exists that should be carefully examined. Remedial

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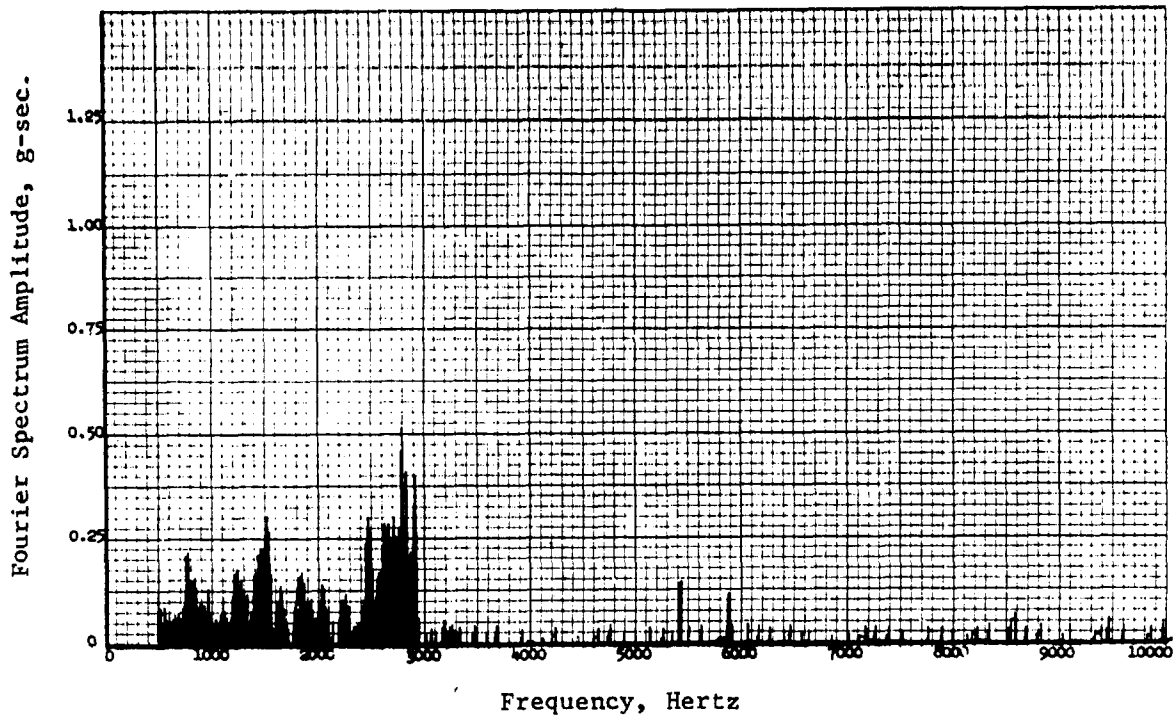
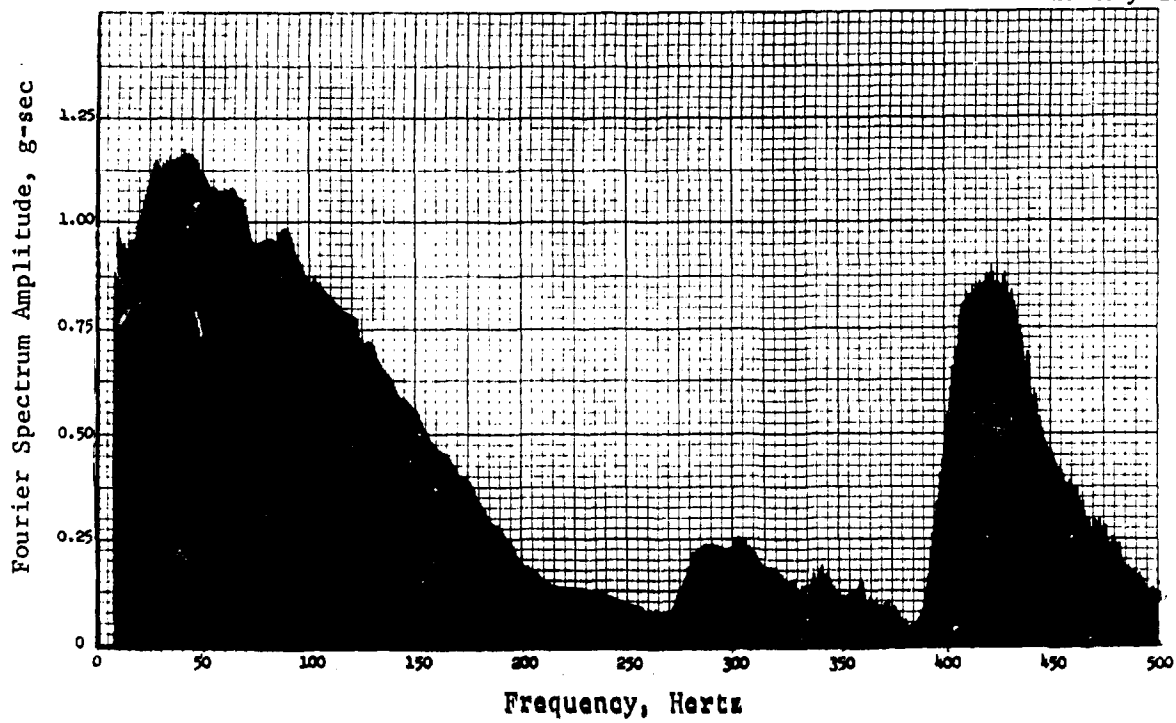


Figure 4: Fourier Spectrum Amplitude Analysis of Shock Pulses  
Using a Spectrum Analyzer

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action consists of either changing the damped natural frequencies of the system (by stiffeners, changes in spring constants or in mass distribution) or introducing shock isolators.

In this latter type of analysis, i.e., comparing the excitation and response spectra, both spectra must be in the same units, i.e., acceleration, velocity, or displacement.

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7. MTP 2-2-808, Field Shock and Vibration Test of Vehicles.

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| 13. ABSTRACT<br><br>This Background Document provides general testing information relative to the measurement of Mechanical Shock affecting Military equipment. This background information supplements and is applied in common to test procedures which deal with evaluation of specific commodity materiel items. |  |                                                                                                                                    |                      |

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