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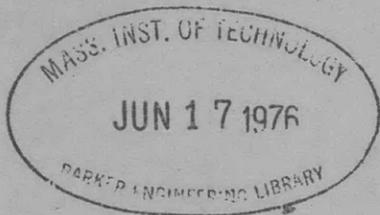
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NAVY DEPARTMENT
DAVID TAYLOR MODEL BASIN
WASHINGTON, D.C.

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PER 1451

TESTS OF ANTIVIBRATION DEVICES FOR RANGEFINDERS
ON THE USS WASHINGTON (BB56)



by

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F. Mintz

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Report R-195

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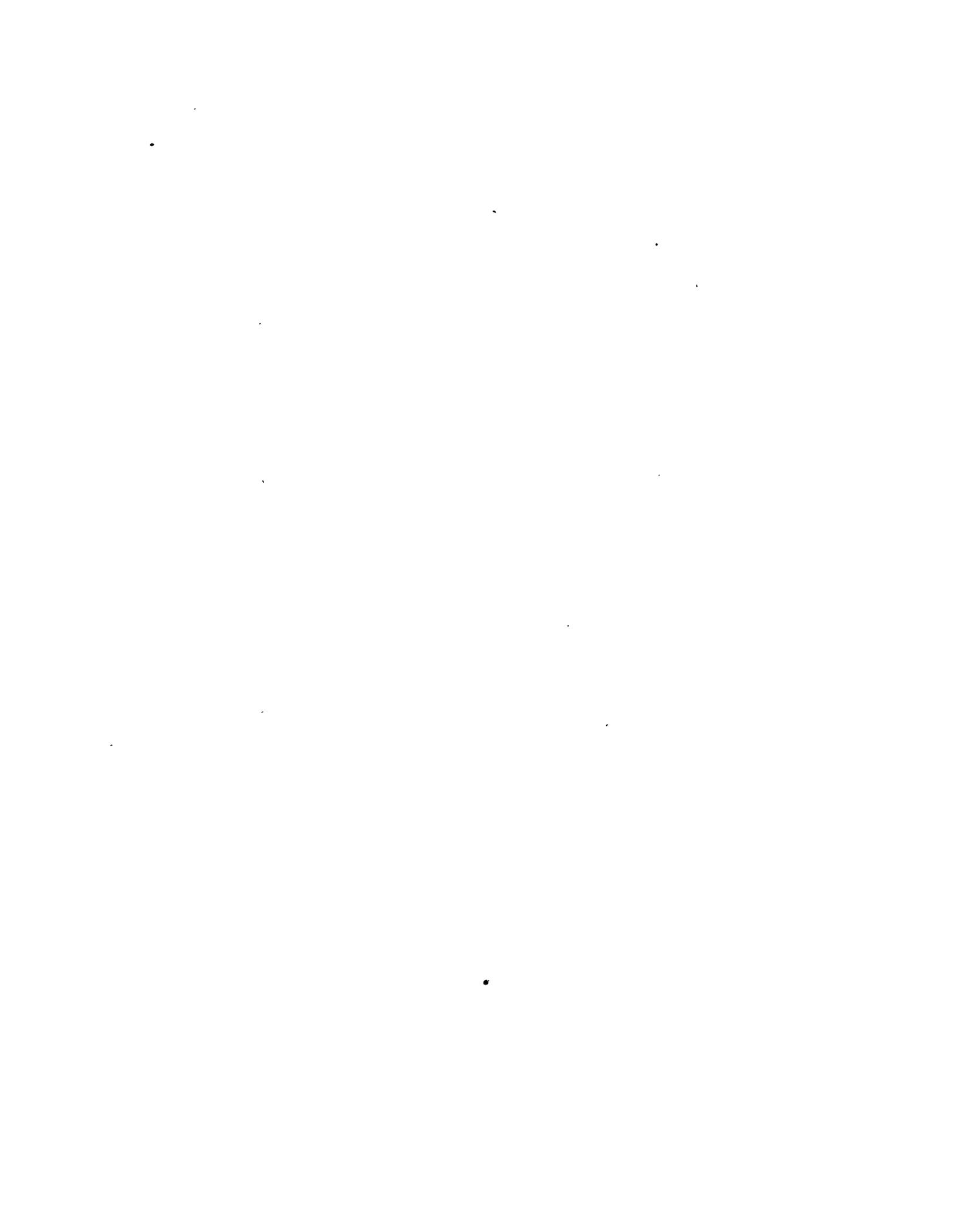
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PERSONNEL

The tests described in this report were performed by personnel of the Scientific and Test Section of the Puget Sound Navy Yard, and by H.F. Kroetch, FC/2C, USN, and F. Mintz of the David Taylor Model Basin. The installation of the antivibration devices was made possible by the cooperation of the Puget Sound Navy Yard, particularly the Director Shop. Many helpful suggestions were made by Capt. J. Ormondroyd, USNR, formerly of the David Taylor Model Basin. The report was written by Mr. Mintz.

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TESTS OF ANTIVIBRATION DEVICES FOR RANGEFINDERS
ON THE USS WASHINGTON (BB56)

ABSTRACT

A set of vibration neutralizers and a set of dashpot dampers, both designed for use on the Mark 48 Rangefinder, were installed on the after and forward main-battery directors, respectively, of the USS WASHINGTON (BB56). In addition, a vibration neutralizer for director towers, which was modified to act as a seismic damper, was installed on the after secondary-battery director. Vibration measurements were made to determine the effectiveness of these antivibration devices and of a set of elastic mounts. The results obtained are presented and discussed, conclusions are drawn regarding the effectiveness of the various devices, and recommendations are made regarding the application and further development of the antivibration devices.

INTRODUCTION

In connection with an investigation of vibration of the Mark 48 Rangefinder, requested by the Bureau of Ordnance (1),* the David Taylor Model Basin has been attempting to complete the development of an effective method of combating the vibration on shipboard of that rangefinder. Preliminary information about the behavior of the rangefinder was reported in a letter to the Bureau of Ordnance (2), in September 1944; on the basis of that information and of discussions with representatives of the Bureau of Ordnance, efforts have been directed principally toward the development and testing of one or more successful antivibration devices.

Of a number of expedients and devices investigated over the period from about June 1944 to June 1945, one device appeared to show considerably greater promise than the rest. This was a set of vibration neutralizers, designed and built at the Taylor Model Basin, which had been modified on several different occasions to cope with practical problems that arose during the course of testing.

By June 1945 the neutralizers appeared to be reasonably effective under laboratory conditions on the rangefinder test stand, and it was considered advisable to perform a test to determine the efficacy of the neutralizers under actual operating conditions aboard ship. A recommendation to this effect was made to the Bureau of Ordnance (3), and the Bureau accordingly authorized installation and testing of the neutralizers on the after main-battery director of the USS WASHINGTON (BB56) (4). The installation was to be made at the

* Numbers in parentheses indicate references on page 37 of this report.

Puget Sound Navy Yard, and the tests were scheduled to be run on or about 25 August 1945.

During the first week of August, a set of dashpot dampers, which had previously been designed for the Mark 48 Rangefinder, were completed and installed in the vibration test stand at the Taylor Model Basin. The dashpot dampers proved highly effective in reducing rangefinder vibration on the test stand; it was accordingly decided to ship them to the Puget Sound Navy Yard and to install them on the forward main-battery director of the WASHINGTON.

Owing to the excellent cooperation of the Puget Sound Navy Yard, no difficulty was experienced in arranging for installation of the dashpot dampers. By the end of August, both these and the vibration neutralizers were installed by Navy Yard personnel under the guidance of the project engineer. This was well ahead of schedule, which had been modified by the cessation of hostilities in mid-August.

During discussions with the Gunnery Department of the WASHINGTON, in connection with the installation and operation of the antivibration devices, it was ascertained that vibration of the after secondary-battery director (Mark 37) interfered with effective operation of the equipment in that director. As it happened, there was at hand at the Taylor Model Basin an experimental vibration neutralizer, intended for use on battery-director towers, which had never been tested on shipboard. In view of this fact and of the general interest of the application, it was decided to install this device on the WASHINGTON, despite its lack of direct connection with the Mark 48 Rangefinder project. The TMB vibration neutralizer for director towers was, therefore, shipped to the Puget Sound Navy Yard and mounted on the after secondary-battery director of the WASHINGTON. On the basis of preliminary tests, discussed later in this report, this neutralizer was modified to a seismic friction damper and was used in this manner for the sea trials.

GENERAL CONSIDERATIONS

Before proceeding with any discussion of the antivibration devices or of the test proper, it may be advisable to consider first certain aspects of the problem of rangefinder vibration and the experimental approach to it. Although some of the points discussed here became apparent only in the light of the test results obtained on the WASHINGTON and others merely summarize the previously unreported results of earlier tests, they will nevertheless be covered here to assist in the logical development of the material contained herein.

RESONANCE OF THE RANGEFINDER TUBE

The rangefinder consists of three main structural parts, as shown in Figure 1: the outer tube, which acts as a protective member and carries bearing rings, insulation, various control knobs, and end windows; the inner tube, which carries principally the end mirrors and is supported at two points inside the outer tube; and the optical bar, a short rigid member which carries the major portion of the optical system and is supported by the inner tube at two points.

The principal cause of undesirable vibration in the Mark 48 Rangefinder is the fact that the outer tube* resonates at a frequency within the range of exciting frequencies of the ships on which these rangefinders are installed. The natural flexural frequency of the tube supported on its bearings is in the neighborhood of 950 CPM. There are two distinct directions or modes of lateral vibration, one vertical and one horizontal, the vertical frequency being 50 to 100 CPM higher than the horizontal. The reason for this is probably that the openings in the tube wall are located in such a manner that the moment of inertia is greater about a horizontal plane than about a vertical plane. When either of the modes of vibration is excited, vibration in the other mode is generally induced by coupling, and occasionally this coupling evinces itself in beats as the rangefinder vibration transfers from one mode to the other, and back again. The Mark 48 Rangefinder is installed on battleships of the BB55 class and of all subsequent classes and on battle cruisers of the CB1 class. The former have a top shaft speed of 200 RPM with 4- and 5-bladed propellers, and the latter have a top shaft speed of 265 RPM with 4-bladed propellers. The maximum exciting frequency is, therefore, about 1000 CPM on the battleships and 1060 CPM on the battle cruisers.

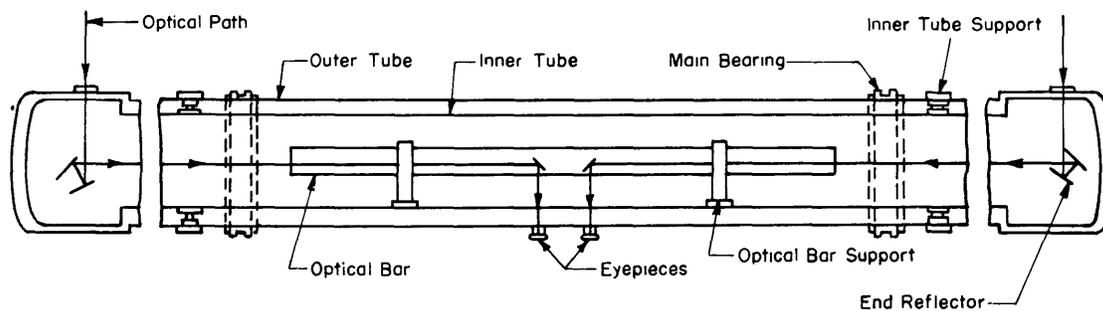


Figure 1 - Schematic Diagram of Inner and Outer Tubes of Mark 48 Rangefinder

* This discussion assumes that the inner tube vibrates with the outer tube. Although this assumption may not be valid at all frequencies, the same general considerations are applicable.

The tube resonance, therefore, falls not only within the exciting-frequency range, but also near the top of that range, where the applied vibration amplitudes tend to be greater. It follows that, if the natural frequency of the tube could be shifted suitably, much of the difficulty due to vibration could be eliminated. In view of the proximity of the natural frequency of the rangefinder to the top of the range of exciting frequencies, the simplest expedient to adopt would be to raise the natural frequency above the exciting range. For practical purposes, a natural frequency of 1200 CPM would be high enough for the present classes of battleships.

As the natural frequency of a uniform prismatic bar in lateral or flexural vibration varies directly as the radius of gyration (other factors remaining constant), the natural frequency of the Mark 48 Rangefinder would be increased to approximately 1200 CPM by increasing the diameter of the outer tube from its present value of 13 inches to a value of about 16 inches, and the inner tube correspondingly. This is an impractical solution to the present problem, for obvious reasons. In the consideration of future designs of rangefinders, however, attempts should be made to keep the natural frequency of the tube well above the expected top exciting frequency.

Experiments have been conducted at the Taylor Model Basin to determine the practicability of increasing the natural frequency of the rangefinder by the addition of T-stiffeners (2). Aside from the practical undesirability of applying such stiffeners in the limited space available in the Mark 38 Directors, in which the Mark 48 Rangefinders are installed, experiments show that the theoretical additional stiffness cannot be attained by any method of attachment of the stiffeners short of welding. Welding has not been resorted to because of the undesirable distortions likely to be produced by the welding process.

EFFECT OF VIBRATION ON RANGING

Vibration of any military device is significant largely in terms of impairment of function, either by reduction of the efficiency of the device or its operator, or by vibration-induced fatigue failure of any of the component parts of the device. In the Mark 48 Rangefinder, impairment of function may be thought of entirely in terms of the reduction of efficiency of the human operator. In the absence of evidence to the contrary, it is considered that failure of component parts is a minor problem.

Vibration of the rangefinder lowers the efficiency of the operator by any or all of the three following effects:

- a. The physiological effect of vibration of the operator's head as it is pressed against the headrest on the rangefinder,

b. The optical effect of vibration of the target in the optical field,

c. The optical effect of vibration of the reticle in the optical field.

It has been proposed that some of the vibration in the optical field caused by rangefinder vibration might be eliminated by proper redesign of certain mountings or attachments inside the rangefinder. The tests performed at the Taylor Model Basin have failed to demonstrate that this is so, but these tests have been admittedly incomplete in this respect. The view at the Taylor Model Basin has been that elimination, that is, reduction to a sufficiently low level, of the vibration would eliminate also the necessity for such internal changes, even if those changes might otherwise improve operation of the rangefinder under vibration.

One of the methods devised in connection with this is the eyepiece camera, discussed later in this report, by which the vibration in the optical field may be measured. Comparison of data obtained by this method with vibration amplitudes of the rangefinder has indicated that there is a rough quantitative relationship between the vibration in the optical field and rangefinder vibration, as well as between these and difficulty of ranging. There appears to be a definite correlation between difficulty of ranging and vertical vibration, but the correlation to horizontal vibration is not so definite (5). On the basis of present knowledge, it is considered that comparison of vibration amplitudes under different conditions yields a fairly good idea of relative difficulty of ranging.

One further point warrants mention here. One rangefinder operator at the Taylor Model Basin has found that experience in ranging under vibration tends to develop a tolerance toward vibration; that is, up to a certain point, the amplitude of vibration tolerable before ranging becomes difficult increases with practice. This leads to the proposal that ranging under vibration be included as part of the training course for rangefinder operators.

VIBRATION-ISOLATING MOUNTS

A frequently applied method of eliminating the vibration of equipment is that of "isolating" the equipment from the vibration of its support by the use of elastic mounts, generally of rubber. Such mounts in their present form were devised for rangefinders by the United States Rubber Company in 1941. A number of these mounts, which will be referred to hereafter as U.S. Rubber or elastic mounts, have been installed and in service on Mark 48 Rangefinders, among others, since about 1943.

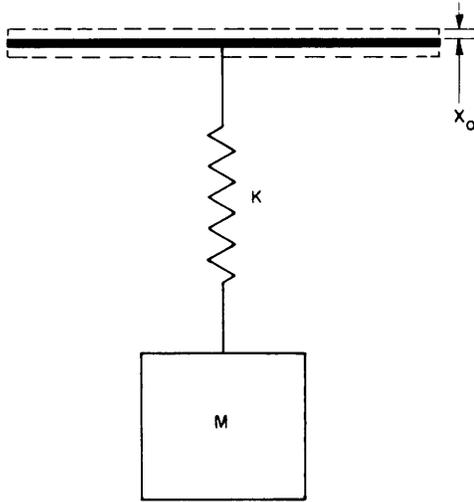


Figure 2 - Idealized Elastically Mounted System

The elastically mounted system is represented by the weight of mass M , supported on the spring of stiffness K . The end of the spring is subjected to an alternating motion of amplitude X_0 . Damping is assumed to be negligible.

The basic principle of the elastic mount is rather simple. The elastically mounted device may be idealized as a weight of mass M on a spring of stiffness K , a vibration of amplitude X_0 being applied to the end of the spring, as shown in Figure 2. Damping is neglected here. This is a system with one degree of freedom, which is discussed in a number of references (6) (7). The amplitude of vibration of M is given by the expression

$$X_m = X_0 \frac{1}{1 - \left(\frac{f}{f_n}\right)^2} \quad [1]$$

where f is the frequency of the applied motion in cycles per second and f_n is the natural frequency of the mass-spring system which is given by

$$f_n = \frac{1}{2\pi} \sqrt{\frac{K}{M}}$$

The efficiency of the elastic mount may be defined as the ratio of the untransmitted amplitude, $X_0 - X_m$, to the applied amplitude, X_0 , or

$$E = \frac{X_0 - X_m}{X_0} = 1 - \frac{X_m}{X_0} \quad [2]$$

It will be noted from Equation [1] that at frequencies $f/f_n \geq 1$, X_m is negative, which means that X_m is out of phase with X_0 . As it is only the ratio of the amplitudes and not the relative phase of the motions that is pertinent to the matter of efficiency, the absolute value of $\frac{X_m}{X_0}$ should be used in Equation [2]; the absolute value is indicated as $\left|\frac{X_m}{X_0}\right|$. Then

$$E = 1 - \left|\frac{X_m}{X_0}\right| = 1 - \left|\frac{1}{1 - \left(\frac{f}{f_n}\right)^2}\right| \quad [2a]$$

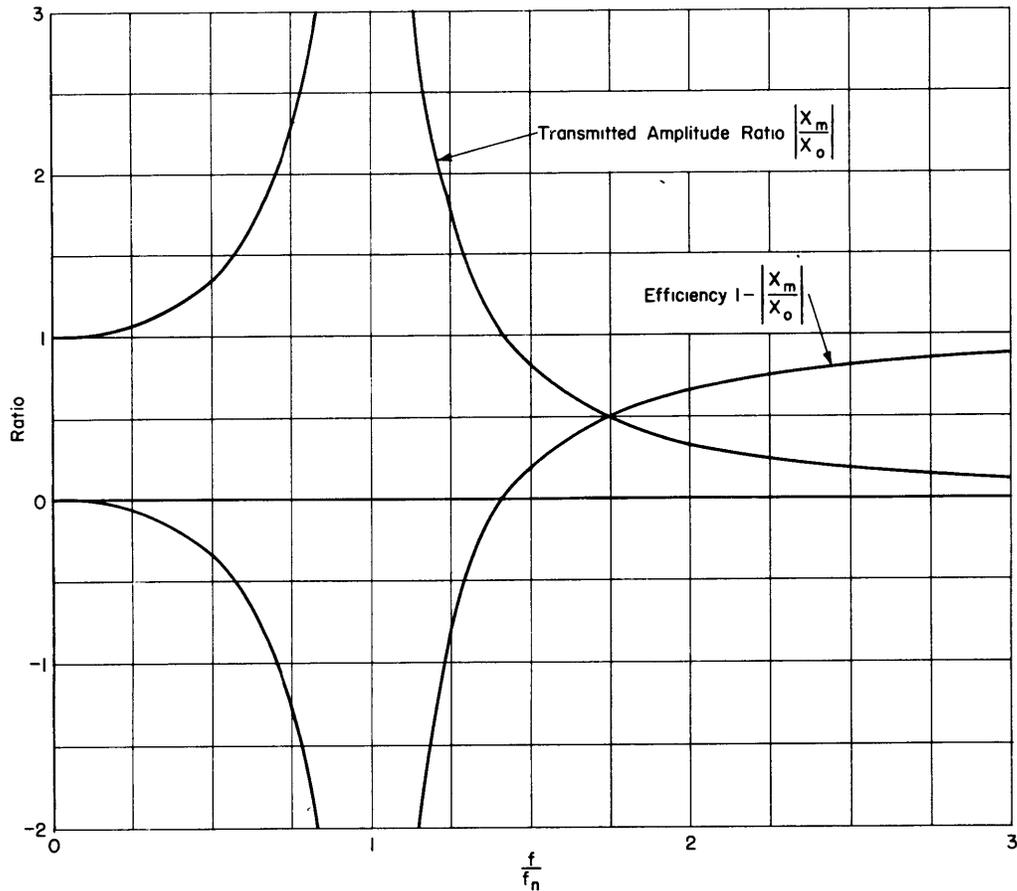


Figure 3 - Variation with Frequency of Transmitted Amplitude Ratio and Elastic-Mount Efficiency

It may be seen that above $f/f_n = 3$ the transmitted amplitude approaches zero (at $f/f_n = 3$, $\frac{X_m}{X_0} = 0.125$) and the efficiency of the mount approaches unity.

A negative efficiency, of course, indicates that X_m is greater than X_0 .

The quantities $\frac{X_m}{X_0}$ and E are plotted on a basis of f/f_n in Figure 3, for assumed zero damping.

The U.S. Rubber mounts are designed to yield a sufficiently low vertical natural frequency of the rangefinder on the mount so that the ratio f/f_n is about 3 or more under ordinary operating conditions. The actual effectiveness of the mounts, however, is not nearly as high as the idealized analysis would indicate. There are a number of reasons for this, the more important of which are listed here:

1. The natural frequency of the mount in the two horizontal directions is considerably higher than the frequency in the vertical direction, so that the transmission of horizontal amplitudes is relatively high. Although it is true, as contended in the U.S. Rubber Company reports (8), that the vertical

vibrations affect ranging most, there is ample experimental evidence to show that horizontal vibration also affects ranging.

2. The rubber "sandwiches" comprising the elastic mounts possess a certain amount of internal damping, which reduces the efficiency of an elastic mount.

3. The previous analysis of elastic-mount action assumed steady-state conditions, which never exist on shipboard. The more or less transient nature of shipboard vibrations affects adversely the efficiency of elastic mounts.

4. Although suspended flexibly, the rangefinder itself still remains an elastic system and reacts as such to the vibrations that pass through the rubber mount. Resonant vibration may therefore occur even though the applied amplitudes of vibration are attenuated by the rubber mounts.

Despite the factors listed, the elastic mounts perform in some installations with reasonable effectiveness under most conditions. It appears, however, that the one condition under which the U.S. Rubber mounts fail to act properly is the one in which they are most needed, namely, during gunfire. Reports from the ships on which U.S. Rubber mounts are installed indicate that the mounts have to be "locked out" almost without exception during the firing of guns, to permit any use at all of the rangefinder (9). The factors previously discussed nullify the isolating effect of the elastic mounts under the shock conditions due to gunfire. This characteristic of the rubber mounts is a serious disadvantage and is the principal reason for the search for a more effective antivibration device.

ANTIVIBRATION DEVICES INSTALLED ON THE USS WASHINGTON

As pointed out previously, three antivibration devices were installed on the USS WASHINGTON. The vibration neutralizers and the dashpot dampers, for the Mark 48 Rangefinder, were installed on the after and forward main-battery directors respectively; the vibration neutralizer for the director tower was installed on the after secondary-battery director.

VIBRATION NEUTRALIZERS FOR MARK 48 RANGEFINDER

The vibration neutralizers for the Mark 48 Rangefinder, shown in Figure 4, consist of two practically identical devices, one mounted on each end of the outer tube. Each neutralizer comprises a clamping ring by which the neutralizer is clamped around the end box of the rangefinder, a frame supporting the springs, and a vibrating element. The element is an electromagnet which, when activated, locks itself against the steel back-plate. The magnet operates on a 110-volt direct current, which is carried in a cable

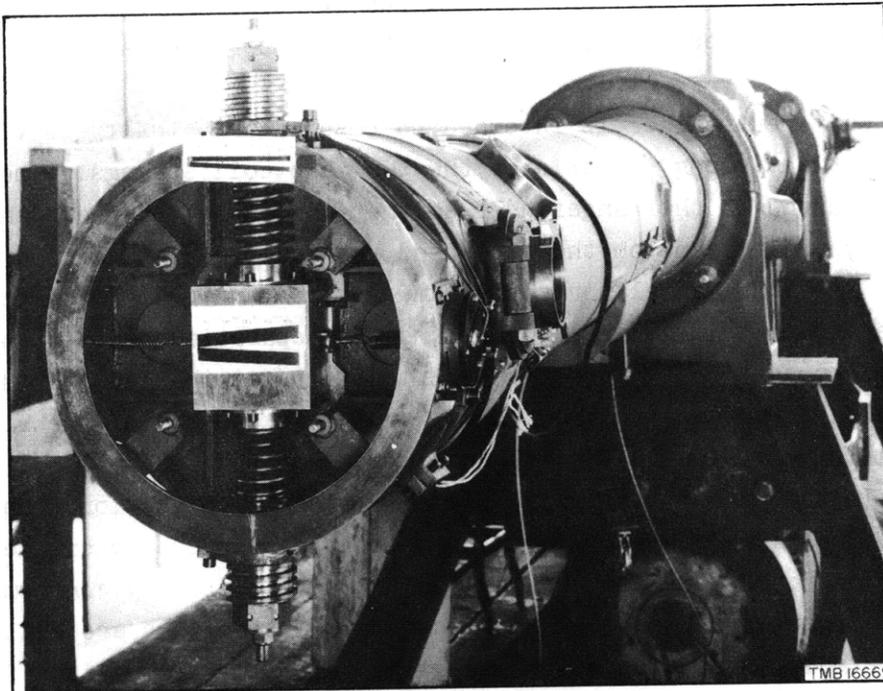


Figure 4a - Close-Up View of the Vertical Neutralizer

The clamping ring, frame, seismic springs, vibrating element, and the phosphor-bronze springs that carry current to the electromagnet are shown.

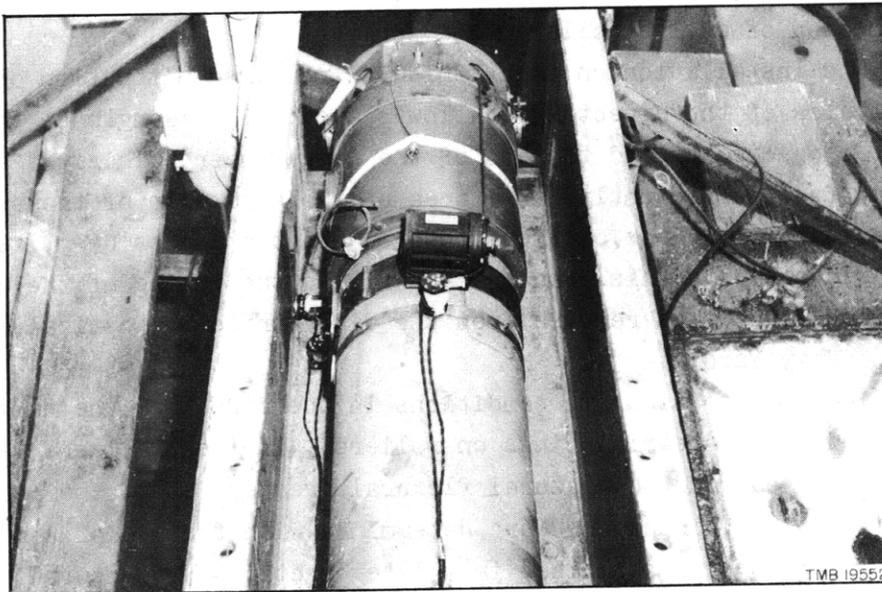


Figure 4b - Vibration Neutralizer Mounted on the Mark 48 Rangefinder in the After Main-Battery Director, USS WASHINGTON

Note the added end box on the shield. This view, looking outboard, with the top plate of the shield removed, shows the right end of the rangefinder with the vertical neutralizer mounted. Vibration pickups are attached to the tube and mounted on the shield proper.

Figure 4 - Vibration Neutralizers for Mark 48 Rangefinder

running along the tube from the control box at the rangefinder operator's position. By switches in this control box, the operator can lock or activate the neutralizers.

Each neutralizer is intended to respond principally to vibrations in one direction, along the axis of the two main coil springs. The neutralizers are mounted on the rangefinder so that the one on the left end acts horizontally and the one on the right end vertically. This method was adopted because the fundamental horizontal and vertical natural frequencies of the rangefinder are not in general equal, and the separation of the two elements permits independent control of them. Experiments at the Taylor Model Basin have shown that when the neutralizer is acting at one end of the rangefinder the neutralizing action is almost equally good at both ends.

In tuning the neutralizers for most efficient action, the aim is to set the neutralizer frequency equal to the natural frequency of the tube with the neutralizers mounted and locked. This does not exactly conform to theoretically correct practice (10), but when the neutralizers are active it gives maximum neutralizing action at the frequency of maximum amplitude found when the neutralizers are locked. As the natural frequency of the neutralizers is originally set slightly higher than the expected frequency, tuning is accomplished chiefly by the addition of flat lead plates that are bolted to the weight. The spring-anchoring device permits increasing or decreasing by one coil the number of active coils of the spring.

The installation on the WASHINGTON required alteration of the overhanging shields of the director to allow space for the length of the neutralizers that projected beyond the end of the rangefinder. This was accomplished by burning off a sufficiently large area of the end plate of the shield and welding on a prismatic box of the same area about 6 inches deep, as shown in Figure 5. To expedite this process, as well as the tuning of the neutralizers, the rangefinder was removed from the director to the optical shop of the Puget Sound Navy Yard.

In order to simulate conditions in the director, the rangefinder was supported at its bearing rings on rollers. The neutralizers were installed and locked, and the natural flexural frequencies in the horizontal and in the vertical directions were determined with the aid of a miniature vibration generator, as described in a later section. The neutralizers, which had previously been calibrated, were then adjusted to the appropriate frequency. A check test showed that there had been no substantial change in the frequencies of the rangefinder after it was re-installed in the director.

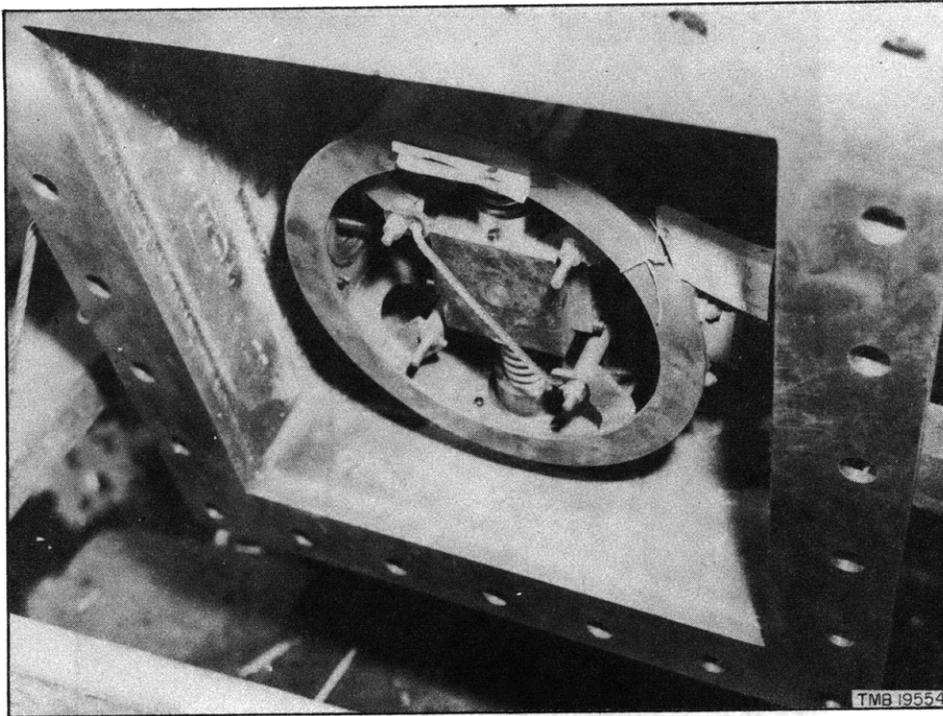


Figure 5 - View of End of Shield Showing the End Box Added to Accommodate the Neutralizers

This view, from outboard and above the right end of the rangefinder, shows the flanged end box which was added to the shield to allow space for the neutralizers. The weight and the springs of the vertical neutralizer are clearly visible.

DASHPOT DAMPERS FOR MARK 48 RANGEFINDER

The dashpot dampers are shown in Figure 6, as installed on the forward main-battery director of the WASHINGTON. The dampers are attached at both ends of the tube by a clamping ring that supports a small shaft at the rangefinder centerline. Two arms, each attached to a dashpot, ride on this shaft on bearings. By this arrangement, motion-resisting forces generated in the dashpot may be transmitted axially along the rods to the rangefinder without imposition of restraint in other directions.

The dashpots are bolted to the outside of the shield by cover plates, one being directly below the rangefinder to damp vertical vibrations and the other in a horizontal plane with the rangefinder centerline for horizontal vibrations. This arrangement differs from the one used in the laboratory tests, in which the dashpots were mounted to simulate installation inside the shield, and a rocker-arm was required to transmit forces from the horizontal dashpot to the rangefinder.

The dashpot proper, in which a piston moves with small clearance in a cylinder filled with oil, opposes rapid alternating motion, such as vibration, but offers little or no restraint to slow, long-period motions such as

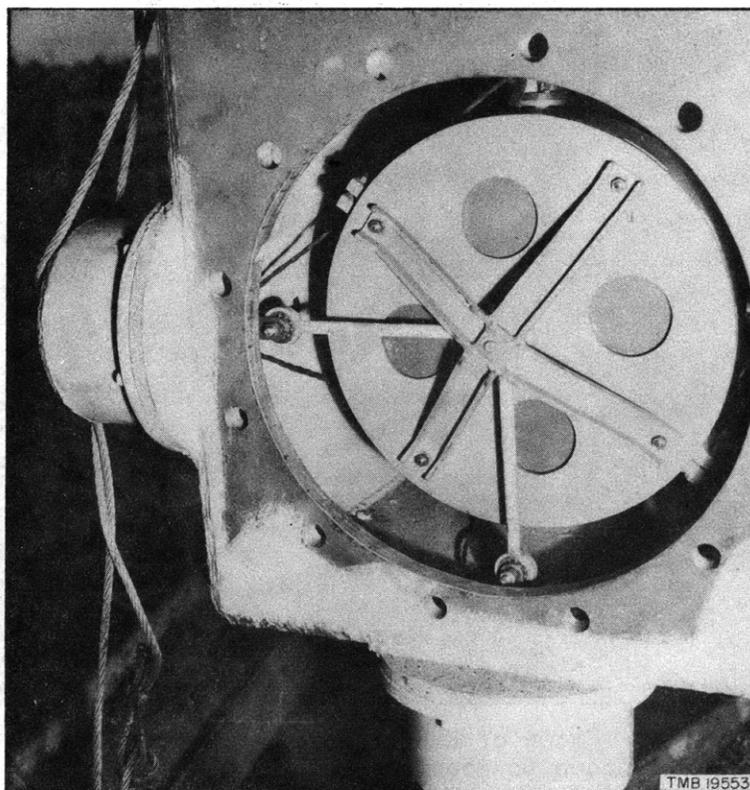


Figure 6 - Dashpot Dampers for Mark 48 Rangefinder Installed in the Forward Main-Battery Director, USS WASHINGTON

In this view of the right end of the rangefinder, the completed installation is shown prior to the mounting of the end plate. The clamping ring is clamped over the end of the tube supporting the connecting rods at the tube axis. The rods, in turn, are bolted to the yoke attachment to the dashpots, which are supported and protected by the dashpot covers.

the relative motions between the rangefinder and the shield due to thermal distortion of the shield.

For this device to be effective, of course, the shield must be rigid relative to the rangefinder, and in addition it must not have a resonant frequency within the range of propeller-excited frequencies encountered on the ship. One of the purposes of the present test was to confirm that this was the case in the Mark 38 Director.

A noteworthy feature of the installation on the WASHINGTON is the fact that it was accomplished without removal of the rangefinder from the director. This was done by cutting a circular hole in the end plate of the shield large enough to permit location and installation of the parts. The rangefinder was protected during the cutting process by asbestos pads which had been inserted through the end window of the shield. The completed assembly was protected from weather by a circular plate bolted over the hole in the end plate.

VIBRATION NEUTRALIZER FOR DIRECTOR TOWER

The vibration neutralizer for the director tower is illustrated in Figure 7. It consists of an adjustable weight on rollers, a set of fixed and adjustable springs, and a steel frame for mounting. The weight, which totals 50 pounds, is made up of a base carrying the rollers and eight removable bars, weighing 3 pounds each, which are bolted to the base.

The stiffness of the adjustable springs is varied by changing the position of a movable clamp along the spring length, thereby changing the number of active coils. The neutralizer frequency may be varied from about 500 CPM to 900 CPM by changing the number of removable bars of the weight and the number of active coils of the springs. This frequency band practically covers the range of director-tower frequencies found on the more recent classes of naval vessels in tests with vibration generators (11).

The weight of 50 pounds was considered to be adequate in the original design, as it was calculated that this weight, vibrating at the allowable single amplitude of 1/2 inch, would neutralize the maximum force developed by the Taylor Model Basin's small vibration generator. Since the amplitudes of resonant vibration caused by this machine in tests on battery directors have been as large as the resonant amplitudes measured during tests underway, the value chosen for the weight appeared to be reasonable.

Preliminary tests, made by vibrating the director with a vibration generator after the neutralizer was welded* to the top of the after secondary-battery director of the WASHINGTON, indicated that the neutralizer was relatively ineffective, although double amplitudes of the vibrating element of

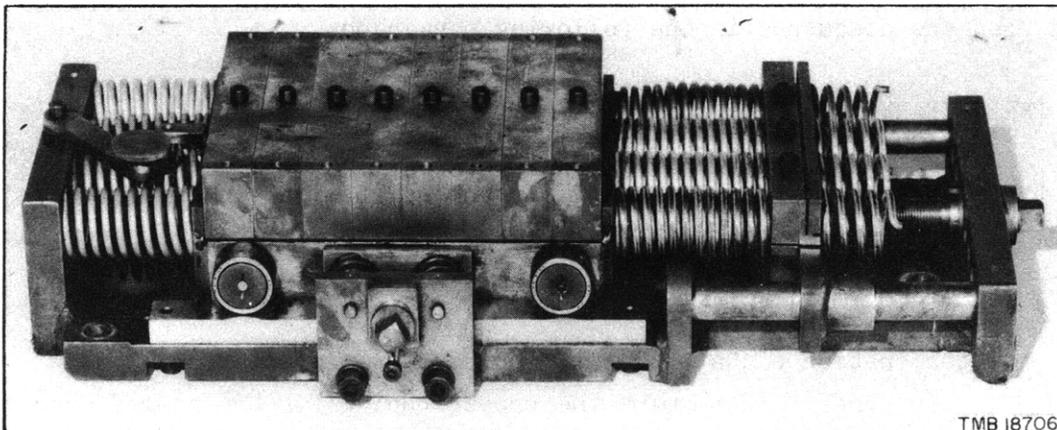


Figure 7 - Vibration Neutralizer for Director Tower

The neutralizer is shown here without the added weights that were used on the WASHINGTON.

* Attempts to mount the neutralizer by clamping it to the director with angle clips proved fruitless, as the vibration was not effectively transmitted by the clamping arrangement.

about 1/4 inch were obtained. This was apparently due to the fact that the ratio of the mass of the vibrating element to the mass of the director was too low to produce an appreciable "spread" of the two new critical frequencies caused by the addition of the neutralizer. The mass ratio, being about 1:1000, produced a spread of about 3 per cent between the two new frequencies, which is too small for practical use.

The appropriate solution was, of course, to increase the mass of the vibrating element, thereby increasing both the frequency spread and the neutralizing effect. This could be readily accomplished, but to retain the proper frequency for neutralizing, the spring stiffness would have to be increased by the same factor as the weight. This was not practicable, however, without designing and building a completely new device. It was decided, therefore, to increase the weight by a factor of about 10, retaining the springs as they were, and to use the device as a friction damper rather than as a neutralizer.

A total of 600 pounds was added to the weight by means of a fabricated steel box that was bolted to the weight and filled with lead pigs. Damping was obtained by tightening the friction plates at the side of the weight. A test with the vibration generator showed that this makeshift damper decreased the resonant amplitude appreciably, and therefore this arrangement was used during the sea trials.

TEST METHODS AND PROCEDURES

The measurements made in preparation for the test run on the WASHINGTON involved the use of standard vibration-measuring equipment; several of the techniques used were not conventional, however. The equipment and methods used are discussed in the following paragraphs.

PRELIMINARY TESTS

Several preliminary tests were run both on the Mark 48 Rangefinder of the after main-battery director and on the after secondary-battery director. The object of the tests was primarily to determine the proper tuning of the neutralizers.

Determination of Natural Frequencies of Rangefinder

In order to determine the proper tuning for the rangefinder vibration neutralizers, it was necessary to determine the fundamental natural frequencies of the rangefinder tube after addition of the neutralizers. This was accomplished by a technique originally suggested by the New York Navy Yard (12). A miniature vibration generator was improvised by bolting an

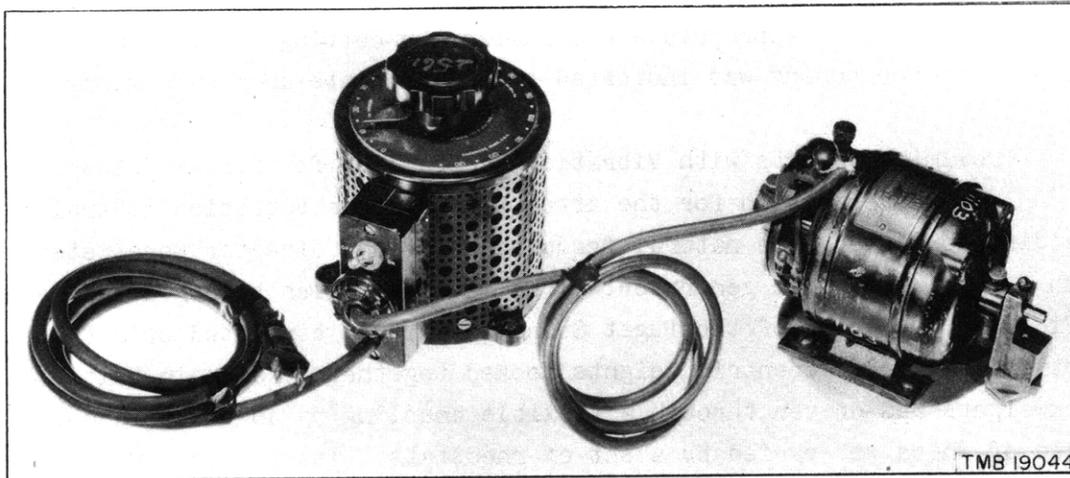


Figure 8 - Miniature Vibration Generator and Control

The generator is a 1/20-HP universal motor, the speed of which is controlled by the Variac. As this is a one-shaft vibration generator, forces are produced in all directions in a plane perpendicular to the shaft axis. In use, the generator is oriented so that this plane includes only one of the two principal directions of motion of the rangefinder.

unbalanced weight to the projecting shaft of a 1/20-HP universal motor. This was fastened to the rangefinder near the end of the tube by a bracket clamped around the tube. The motor speed was controlled with a variable-voltage transformer, or Variac. The generator and control are shown in Figure 8.

This method of determining the tube frequency is superior to the previously used method of striking the tube with the hand and observing the frequency of the resultant free vibrations. Although the free-vibration method possesses the advantage of requiring a minimum of equipment, the results obtained are not always consistent.

The initial determination of frequency was made with the rangefinder out of the director, from which it had been removed to allow the required modification in the shield to be made. The rangefinder was set on a pair of roller supports on the floor of the optical shop, the supports being located at the bearing rings of the rangefinder. In determining the horizontal frequency, the vibrator was mounted with the shaft vertical, to produce forces in a horizontal plane. The speed was adjusted until resonance was reached, when the frequency was determined with a set of Frahm's reeds and checked with a Strobotac. A similar procedure was used for the vertical natural frequency, except that the vibrator was oriented to produce forces in a vertical plane parallel to the centerline of the tube. These frequencies were, of course, determined with the neutralizers mounted on the tube and locked. The frequencies were checked by the same procedure after the rangefinder had been reinstalled in the director. In both the optical shop and the director, the proper tuning of the neutralizers was checked by vibrating the tube in a

vertical or horizontal plane at resonance with the neutralizers locked and then activating the appropriate neutralizer by cutting off the current to the magnet. Proper tuning was indicated by an immediate decrease in amplitude.

Preliminary Tests with Vibration Neutralizer for Director Tower

In preparation for the attempt to use the vibration neutralizer for the director tower, the natural frequencies of the director were determined with a small vibration generator. This machine, which belonged to the Scientific and Test Group of the Puget Sound Navy Yard, consisted of a frame supporting a pair of eccentric weights hooked together by a chain belt. One of the weights was driven through a flexible coupling by an electric motor, the speed of which was varied by a set of rheostats. The vibrator was welded to the side of the director near the top, to produce vibration along the tube axis. The resonant frequency was obtained with the director trained both aft and athwartships.

The neutralizer was tuned to 750 CPM, the athwartship frequency of the director, by adjusting the weights and springs in accordance with previously determined calibration curves. It was oriented to vibrate along the rangefinder axis and welded to the top of the director. When a preliminary test with the vibration generator failed to show any decrease in the vibration of the director, it was decided to add 600 pounds of weight as described previously, and to use the device as a damper. The damper was tested by vibrating the director with the friction plates loose (damper inactive), partially tightened (damper partially active), and fully tightened (damper active).

All vibration measurements in this series of tests were made with Puget Sound Navy Yard instruments. A General Radio vibration pickup was clamped to a stiffener on the director. Its signal, amplified in the General Radio vibration meter and a Brush amplifier, was recorded on a Brush direct-inking oscillograph.

VIBRATION MEASUREMENTS DURING SEA TRIALS

During the sea trials, vibration measurements were taken in the three directors in which antivibration equipment was installed. These locations, shown in Figure 9, were the forward main-battery director, the after main-battery director, and the after secondary-battery director.

Vibration Measurements in After Main-Battery Director

Vibration of the after main-battery director and the rangefinder was determined in two ways: first, by measurement of vibration amplitudes, and second, by motion-picture recording of the vibration of the optical field.

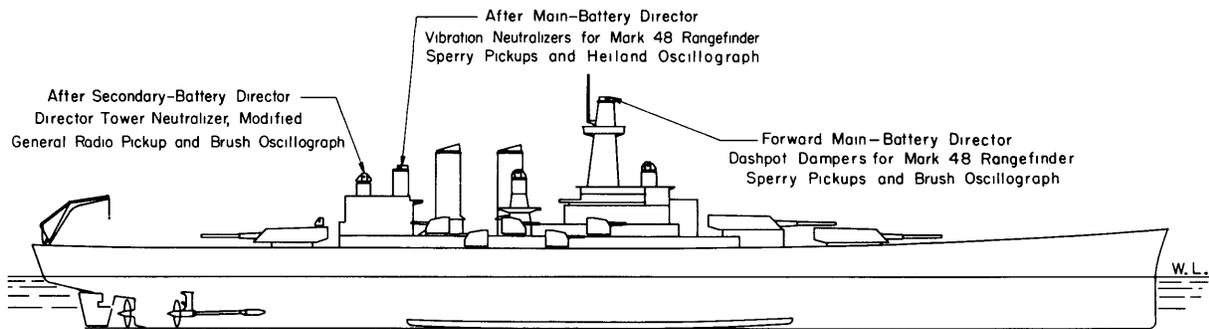


Figure 9 - Location of the Three Directors in Which Antivibration Devices and Measuring Equipment Were Installed

Vibrations were recorded with Consolidated Engineering (Sperry-MIT) vibration pickups recording directly into a 6-channel Heiland oscillograph through a step-resistance attenuator. Vertical vibrations were measured with small vertical pickups at the following locations: the right end of the shield, the right end of the rangefinder, and on the director at the right bearing bracket. Horizontal vibrations were measured at the same locations, a small horizontal pickup being used at the right end of the shield and large horizontal pickups at the other two locations.

The small and the large Sperry pickups are identical in principle, differing only in natural frequency and method of guiding the moving magnet. Both instruments develop, by means of a seismically mounted permanent magnet moving relative to a coil fixed to the instrument case, a voltage proportional to the vibration velocity. In the large pickup the magnet, guided by rollers, moves in a cylinder which is filled with oil and has provision for adjusting the damping. In the small pickup, the magnet is guided by a rod projecting through a hole in the center of the magnet. Although the pickup was originally intended to be filled with oil, it has been found that leaving in just enough oil to provide lubrication improves the response of the pickup at low frequencies. A schematic diagram of the small pickup is shown in Figure 10.

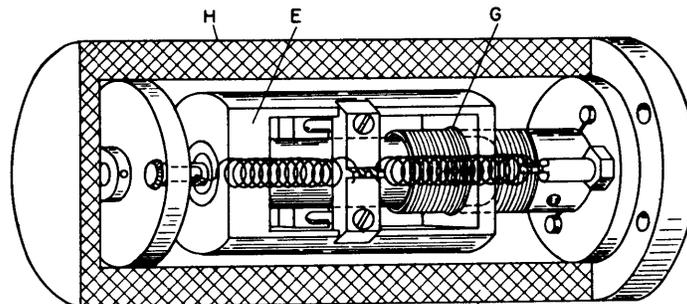


Figure 10 - Essential Parts of Sperry-MIT Vibration Pickup

The pickup unit comprises a case H containing a spring-supported seismic element E which is itself a permanent magnet whose flux cuts the turns of a coil G fixed in the case. A voltage is generated in the coil proportional to the relative velocity between the coil and the seismic element.

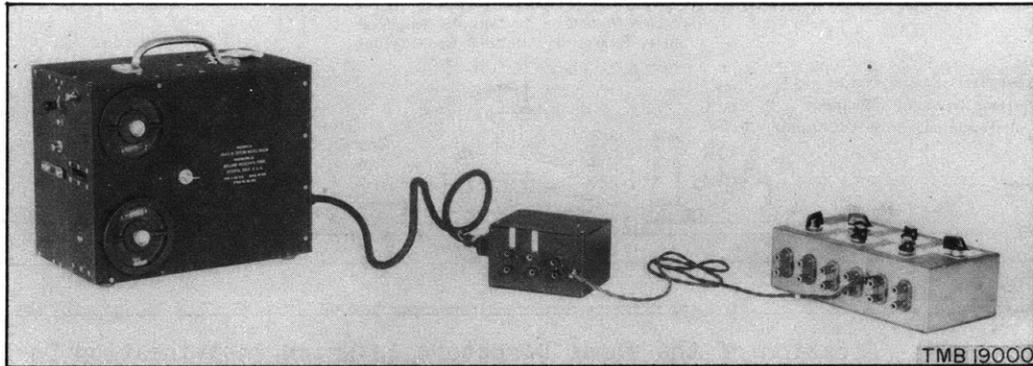


Figure 11 - Heiland Oscillograph and Attenuator

The Heiland oscillograph, shown in Figure 11 with the attenuator, is a compact 6-channel string oscillograph, using a self-contained storage battery as the source of the required power. The 6 channels are recorded on 2-inch photographic paper which is inserted in 100-foot rolls. The galvanometers are extremely sensitive, giving a deflection of 1 inch on the recording paper for a current of about 400 microamperes. In order to keep the record within reasonable limits of size, a 6-channel 10-step attenuator was used in series with the pickup.

As the record obtained is one of vibration velocity rather than displacement, the records were analyzed to determine the velocity amplitude. The portions of the record analyzed were reasonably sinusoidal, permitting calculation of the vibration amplitude without appreciable error by the formula $X = V/\omega$, where X is the vibration amplitude, V is the velocity amplitude, and ω is the "circular" frequency, i.e., 2π times the frequency in cycles per second. A sample record is shown in Figure 12.

Vibration of the optical field was recorded with a 16-mm electrically driven motion-picture camera supported in position at the eyepiece by a bracket, designed by Bausch & Lomb Optical Company for this purpose. The

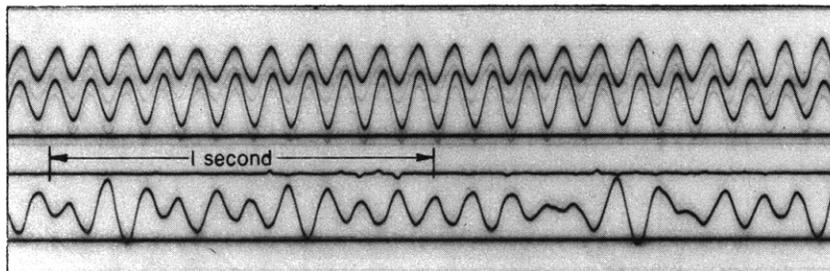


Figure 12 - Sample Heiland Oscillograph Record

This is Record 16, taken in the after main-battery director at 131 RPM. The 0.01-second timing lines usually obtained in these oscillograms are missing, owing to a defective switch. Timing is obtained from known approximate speed of paper and known shaft RPM.

camera was run at a speed of about 60 frames per second. A unit-power telescope mounted opposite the left eyepiece permitted lining up the rangefinder on an available target. The horizon was often the only available target, as records were taken at definite angles of train irrespective of the orientation of the ship. Figure 13 shows the bracket with camera and telescope mounted on the rangefinder. A typical set of eyepiece photographs is reproduced in Figure 14.

To obtain as complete a picture as possible of the behavior of the rangefinder in the director, records of vibration were taken both by oscillograph and by eyepiece camera at intervals of propeller shaft speed of about 10 RPM from 120 RPM to 190 RPM,* with the director trained at 90 degrees and at 180 degrees. Two series of records were taken, the first with the rubber mounts locked continuously and the second with the rangefinder floating continuously on the rubber mounts. In both of these series vibration was recorded with the neutralizers locked and active. In addition, vibration was recorded during turns at three speeds and all four conditions.

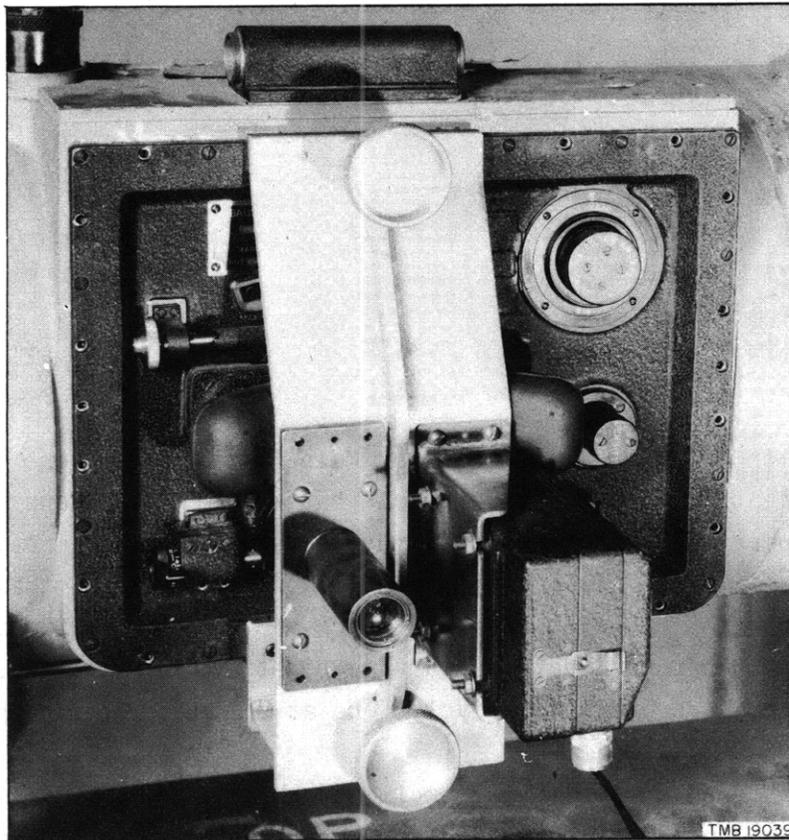


Figure 13 - Eyepiece Camera and Bracket Mounted on Mark 48 Rangefinder

* Owing to an overheated bearing, the port inboard shaft could not be run above 150 RPM. Its speed was maintained at this value during the runs in which the speed of the other shafts was greater than 150 RPM.

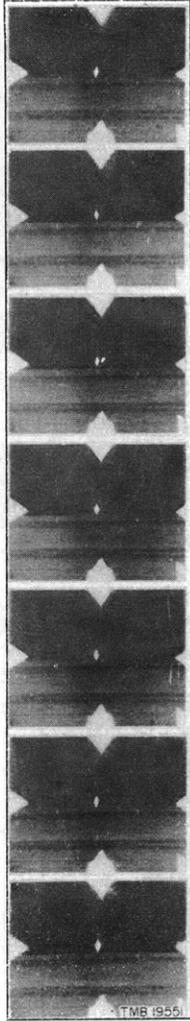


Figure 14 - Sample Record of Optical Field Taken with Eyepiece Camera

This is one of the best exposed portions of film obtained. Many of the records were either underexposed or showed no horizon owing to presence of fog during the test run. The "target" was the horizon, which is seen in the photographs as the line of separation between the dark area (sky) and the lighter area (water). As reversal film was used, the print is negative.

Vibration Measurements in Forward Main-Battery Director

Vibrations in the forward main-battery director were recorded by the use of Sperry-MIT pickups and a Brush amplifier and direct-inking oscillograph. Four pickups were used: A small horizontal and a small vertical pickup at the right end of the rangefinder, and a large horizontal and small vertical pickup on the director, near the right bearing support. The signals from these were recorded successively, one at a time, at each speed and condition.

The Brush direct-inking oscillograph is a device utilizing a piezo-electric crystal which actuates a recording pen. The oscillations of the pen are recorded in ink on a moving chart. The oscillograph is generally used as it was in the present test, with an amplifier providing adjustable gain to a maximum of 100,000. The amplifier contains a calibrating circuit which provides a test voltage for adjusting the gain to an appropriate value.

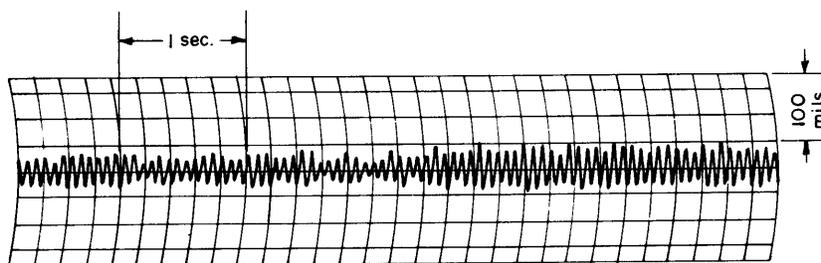


Figure 15 - Sample Record Obtained from Sperry-MIT Pickup on Brush Oscillograph

This record was taken in the forward main-battery director at 180 RPM with the dashpot damper inactive.

Records were taken at the same set of speeds and turns as in the after director, at train angles of 0 degree and 90 degrees, both with the dampers attached to and with the dampers disconnected from the rangefinder. The records obtained with this equipment were analyzed for amplitude of the vibration velocity, and the amplitude of vibration was calculated in the conventional manner. A sample record is shown in Figure 15.

Vibration Measurements in After Secondary-Battery Director

Vibration of the after secondary-battery director Mark 37 was measured in a direction parallel to the tube axis with a General Radio crystal vibration pickup. This instrument was used in the manner previously described for the preliminary test on this director. The pickup signal, which is proportional to acceleration, was subjected to double integration in the General Radio vibration meter, amplified in the Brush amplifier and recorded on the direct-inking oscillograph. A sample record is shown in Figure 16.

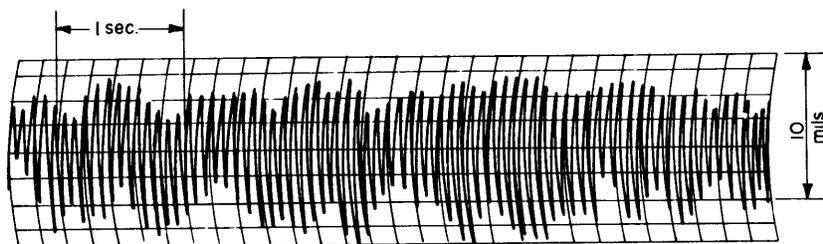


Figure 16 - Sample Record Obtained from General Radio Pickup on Brush Oscillograph

This record was taken on the after secondary-battery director at 120 RPM with the seismic damper active.

The same recording schedule followed in the other two directors was used in the Mark 37 Director. Records were taken with the damper active (friction plates tightened) and with the damper inactive (friction plates loose).

TEST RESULTS

The test results obtained are presented in the following paragraphs.

PRELIMINARY TESTS

The information required for proper tuning and modification of the neutralizers was obtained in the preliminary tests.

Natural Frequencies of Mark 48 Rangefinder

The fundamental natural frequencies of the rangefinder with the neutralizers mounted and locked, and the rangefinder supported on rollers on the floor of the optical shop were found to be

Horizontal Flexure	720 (± 10) CPM
Vertical Flexure	810 (± 10) CPM

With the rangefinder mounted in the after main-battery director of the WASHINGTON, rubber mounts locked, the natural frequencies were found to be

Horizontal Flexure	700 (± 15) CPM
Vertical Flexure	815 (± 15) CPM

The horizontal neutralizer, which had been tuned to about 725 CPM, was re-tuned to about 700 CPM to allow for the change in frequency; the vertical neutralizer was allowed to remain at a natural frequency of about 810 CPM.

Effectiveness of Director-Tower Damper

The tests with the director-tower neutralizer used in its original form showed that the neutralizer had no noticeable effect on the vibration of the after secondary-battery director, although the element itself resonated with a double amplitude of about $1/4$ inch when the director was vibrated at its critical frequency of 750 CPM.

The results of the vibrator tests on the director with the neutralizer modified to act as a seismic damper are plotted in Figure 17. The curves of amplitude against frequency show the behavior of the director with the damper free (inactive), the damper partially active (pressure applied to the friction plates), and the damper fully active (maximum pressure applied to the friction plates). It may be seen from the curves that the resonant amplitude was reduced 30 per cent with the damper fully active and 22 per cent with the damper partially active.

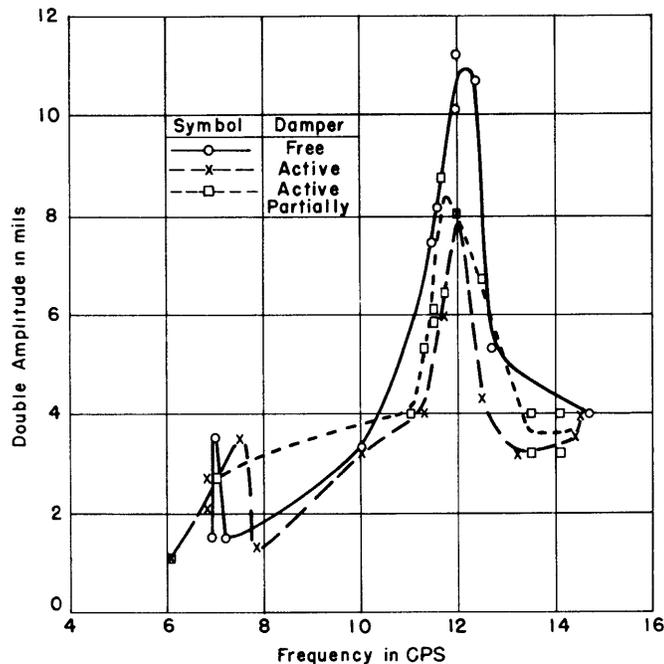


Figure 17 - Amplitudes of Vibration of the After Secondary-Battery Director at Different Settings of the Seismic Damper

The seismic damper was prepared from the director neutralizer by the addition of 600 pounds to the element. The director was vibrated with a vibration generator belonging to the Puget Sound Navy Yard.

SEA TRIALS

Many vibration data were obtained during the sea trials of the WASHINGTON. The data obtained in the various directors are presented separately.

Vibrations in After Main-Battery Director

The results of the measurements on the after main-battery director during sea trials on 10 and 11 September 1945 are plotted in Figures 18, 19, 20, and 21. The significance of these curves is discussed under "Discussion of Results."

Figures 18 to 21 show the curves of vibration amplitude against propeller RPM for the pickup stations at the right end of the rangefinder (vertical and horizontal), at the right bearing of the rangefinder on the director (vertical), and at the right end of the shield (horizontal). No vibration records were obtained from the vertical pickup inside the director near the right bearing pedestal or from the horizontal pickup at the right end of the shield. As the circuits were checked several times during the test and found to be in good working order, it is presumed that the double amplitudes at these stations did not exceed, say, 3 mils. Vibration amplitudes of this magnitude might have occurred without causing the pickups to

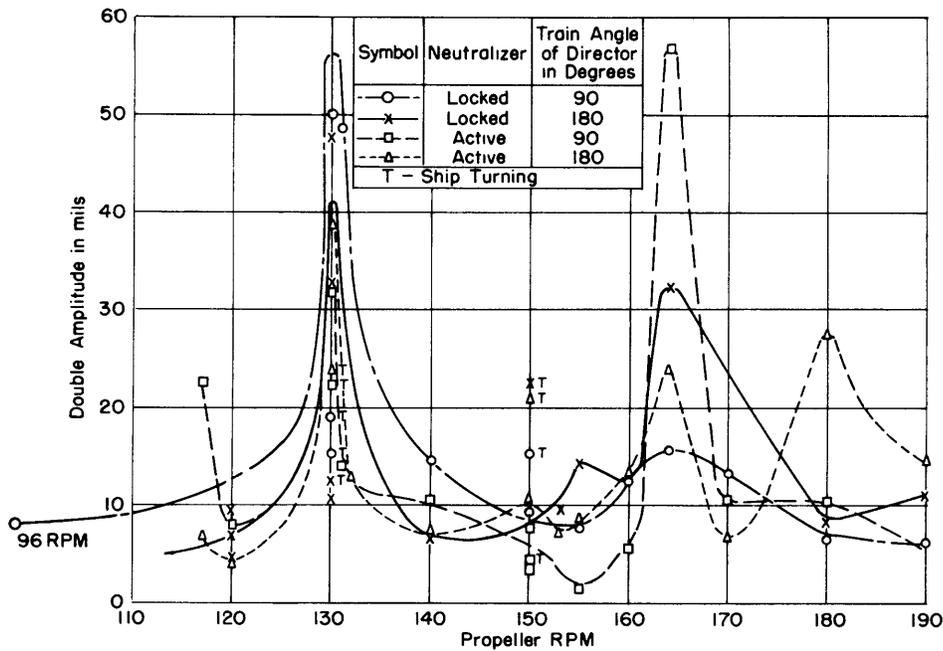


Figure 18a - Rubber Mounts Locked

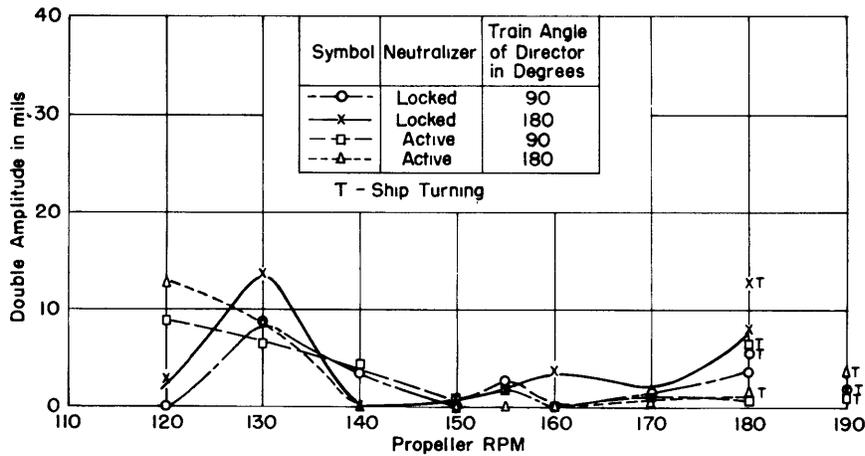


Figure 18b - Rubber Mounts Active

Figure 18 - Amplitudes of Vertical Vibration of the Right End of the Rangefinder, After Main-Battery Director

respond, owing to the inherent friction in the small pickups. Practically all the vibration recorded was of the fifth order, i.e., its frequency in CPM was 5 times the shaft RPM.

The amplitude of vibration of the target in the optical field, as determined from analysis of the eyepiece camera films, is plotted in Figure 22. The data taken with the rubber mounts locked are shown in Figure 22a and with the rubber mounts active, in Figure 22b. Because the target field was continually changing as the ship maneuvered, the horizon was the only

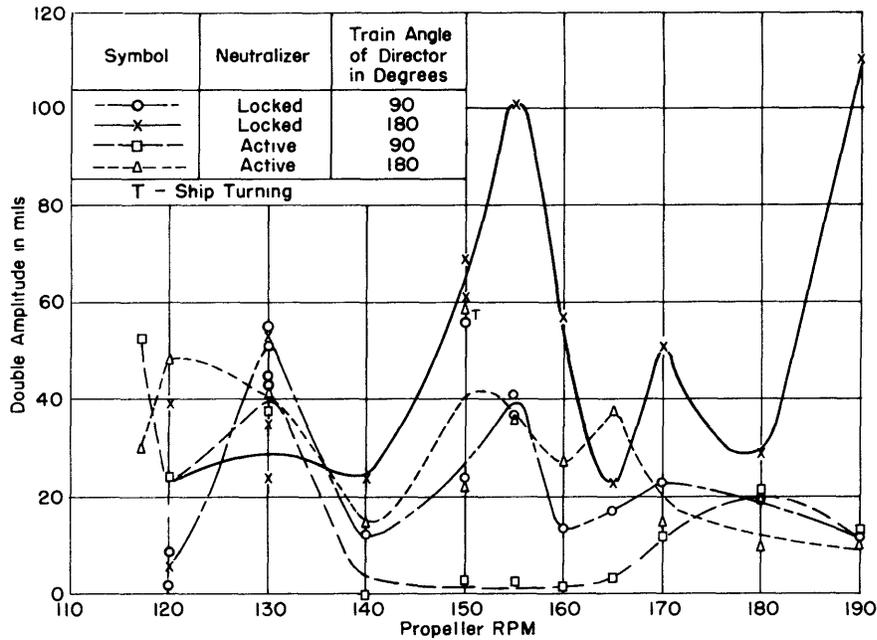


Figure 19a - Rubber Mounts Locked

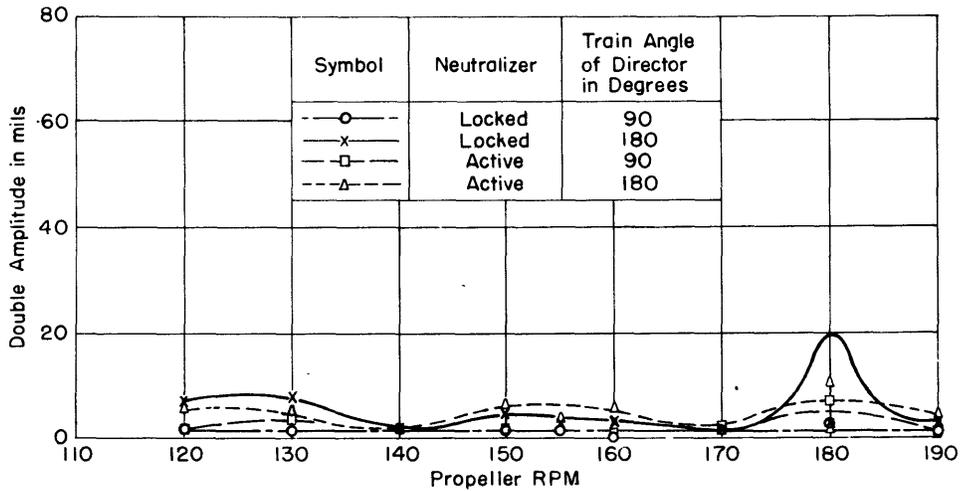


Figure 19b - Rubber Mounts Active

Figure 19 - Amplitudes of Horizontal Vibration of Right End of Rangefinder, After Main-Battery Director

target generally available, and the films were analyzed for the vibration of the horizon. Records obtained at certain speeds could not be analyzed, owing to the presence of fog during those portions of the test runs.

Vibration of the reticle in the optical field was so slight that effective measurements could not be made. Even at the worst conditions, as indicated by other data, the amplitude of reticle vibration scarcely exceeded the error of measurement.

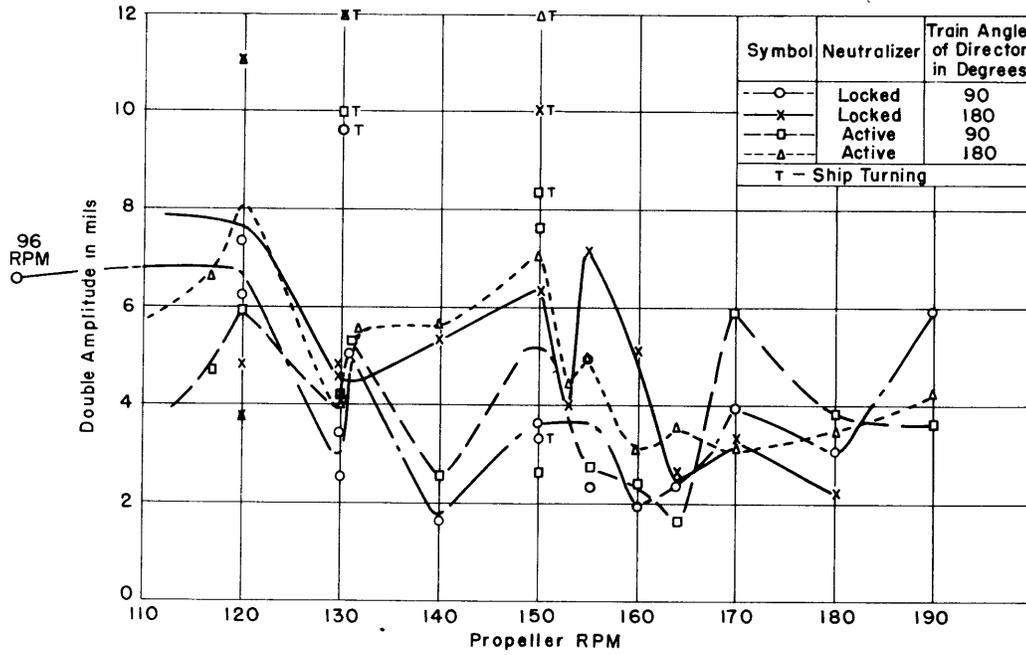


Figure 20a - Rubber Mounts Locked

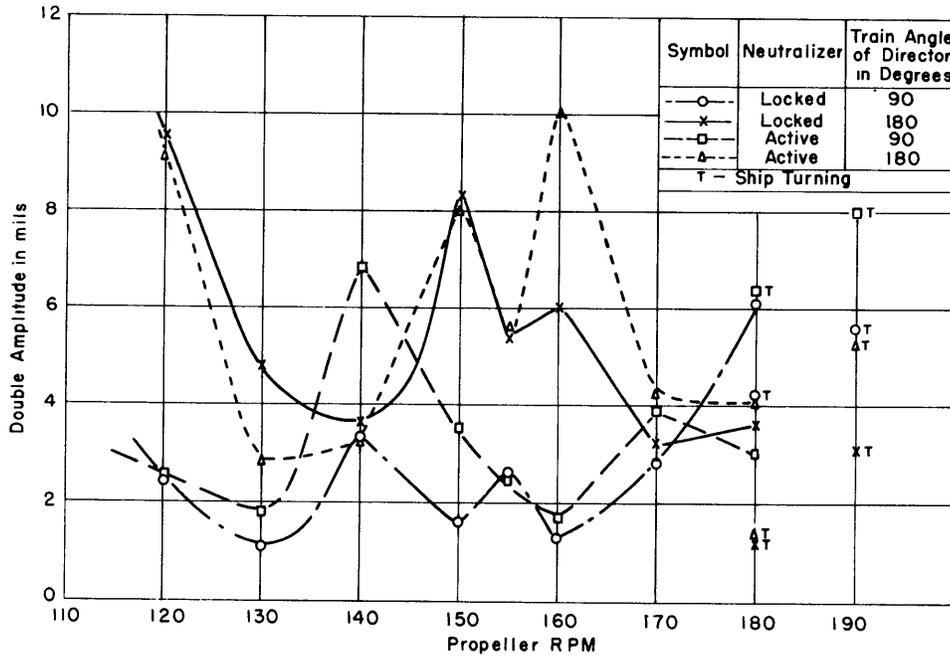


Figure 20b - Rubber Mounts Active

Figure 20 - Amplitudes of Horizontal Vibration at Right Bearing Pedestal, After Main-Battery Director

Note that the amplitude scale in these curves is considerably smaller than the amplitude scale in Figures 18, 19, and 21. The amplitudes plotted here are amplitudes applied at the bearing support, which are expected to be smaller than the amplitudes of vibration of the rangefinder.

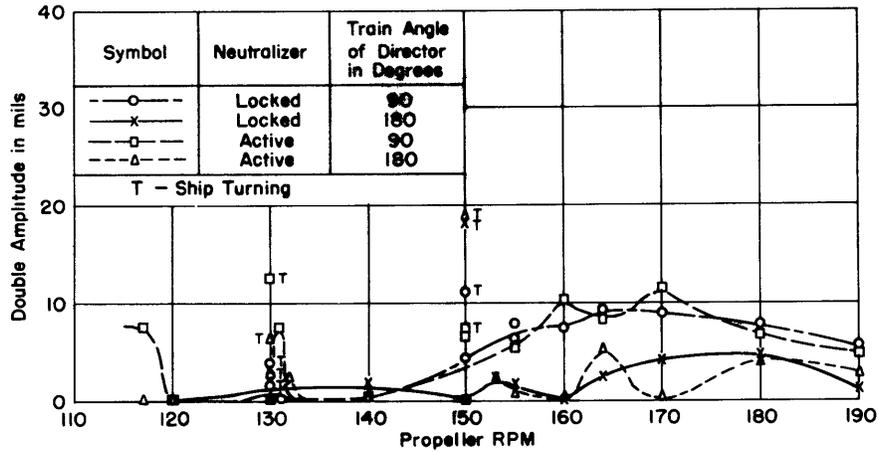


Figure 21a - Rubber Mounts Locked

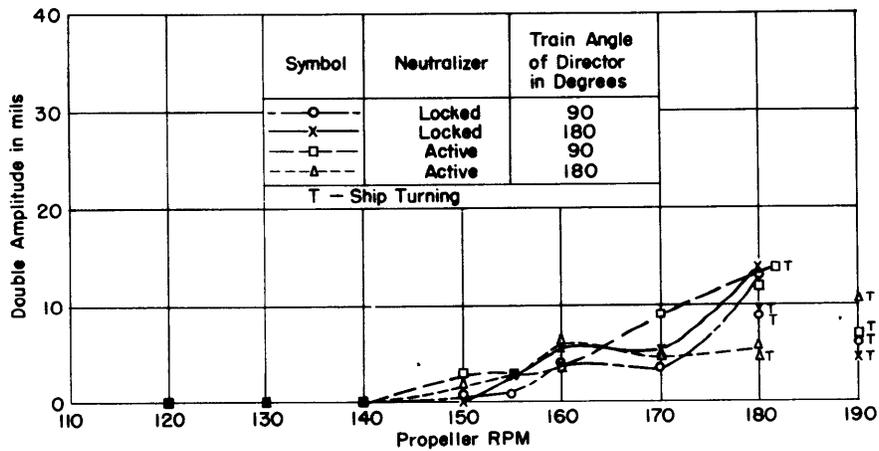


Figure 21b - Rubber Mounts Active

Figure 21 - Amplitudes of Vertical Vibration of Right End of Shield, After Main-Battery Director

The amplitude scale used here is the same as that used in Figures 18 and 19. The vibration amplitudes of the shield are thus more readily compared with those of the rangefinder. This permits making an estimate of the probable effectiveness of the shield as a base for the dashpot damper; see "Discussion of Results."

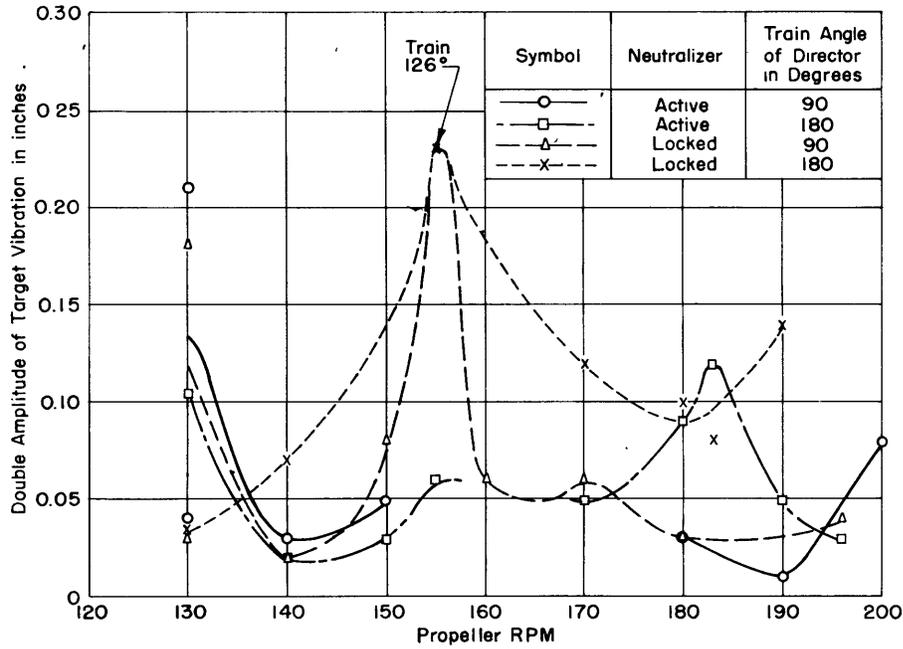


Figure 22a - Rubber Mounts Locked

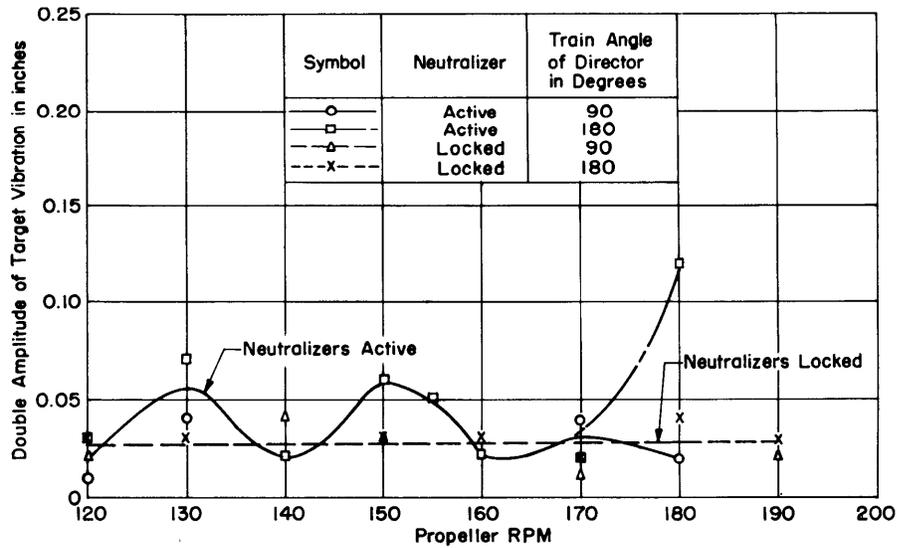


Figure 22b - Rubber Mounts Active

Figure 22 - Amplitudes of Vibration of the Target in the Optical Field, Determined from Eyepiece Camera Films

On the scale used for the amplitude of the target vibration the height of the diamond shown in Figure 14 was 0.11 inch.

Vibrations in Forward Main-Battery Director

The vertical vibrations measured at the right end of the rangefinder, both with and without the dampers acting, are shown plotted on a basis of propeller shaft RPM in Figure 23. This was the only station at which vibrations were detected at a sufficient number of speeds to give a resonance curve.

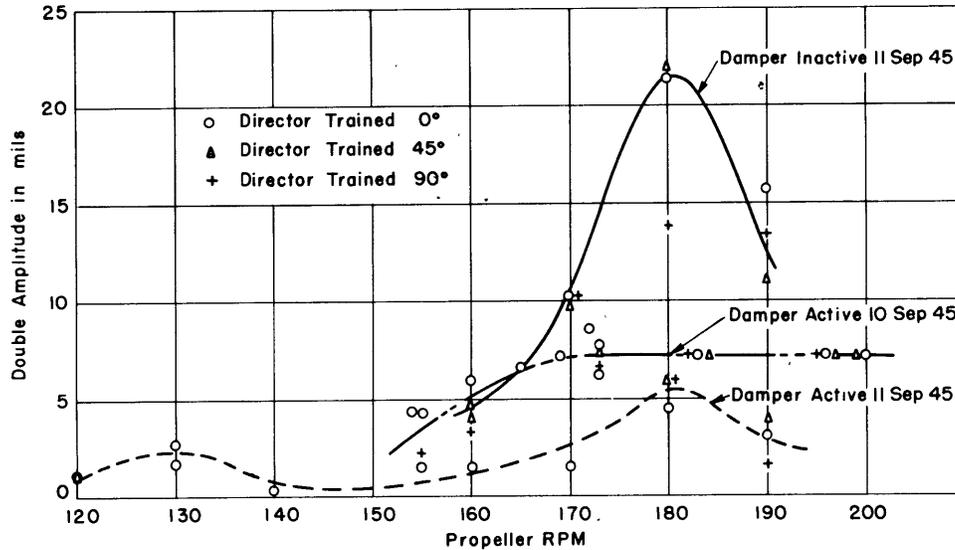


Figure 23 - Amplitudes of Vertical Vibration at Right End of Rangefinder, Forward Main-Battery Director

In addition to the points plotted, which were all obtained while the ship was on a straight course, vibration amplitudes were recorded at this station while the ship was turning. The amplitudes measured, which were appreciable only with the dampers inactive, are listed in Table 1.

TABLE 1

Amplitudes of Vertical Vibration at Right End of Rangefinder during Turns, Forward Main-Battery Director (Dashpot Dampers Inactive)

Shaft RPM	Double Amplitude mils	Director Train Angle, degrees	Rudder
180	11.6	0	Standard Port
180	23.7	45	Standard Port
170	8.9	0	Standard Starboard
170	13.5	45	Standard Starboard
150	8.9	0	Standard Port

TABLE 2

Amplitudes of Horizontal Vibration at Right End of Rangefinder,
Forward Main-Battery Director (Dashpot Dampers Inactive)

Shaft RPM	Double Amplitude mils	Director Train Angle, degrees	Rudder
170	65	0	No turn
170	65	90	No turn
180	60	45	Standard Starboard
170	70	0	Standard Starboard

Horizontal vibrations at the right end of the rangefinder were detected only with the dampers inactive, as shown in Table 2.

No horizontal vibration was detected with the damper active, or at any speeds other than those shown in Table 2 with the damper inactive. It is probable, however, that vibrations of the order of 5 to 10 mils may have occurred without being detected by the small horizontal pickup used, as this type of pickup is susceptible to friction errors.

At the station inside the director near the right bearing pedestal, no vertical vibrations were observed at any time during the test. Horizontal vibrations recorded at this station were well below 1 mil double amplitude at practically all speeds, attaining a maximum of 2 mils double amplitude at 196 RPM with the dampers active.

Vibrations in After Secondary-Battery Director

The amplitudes of vibration in the direction of the rangefinder axis measured on the after secondary-battery director are plotted in Figure 24. These curves show the variation of vibration amplitude with shaft RPM for the damper both active and inactive. For clarity, the data for 180-degree train and for 270-degree train are shown in separate curves.

DISCUSSION OF TEST RESULTS

It is obvious from the test results presented that the various anti-vibration devices differed greatly in effectiveness. The significance of the results obtained is discussed here, with particular emphasis on the effectiveness of the antivibration devices.

RANGEFINDER VIBRATION IN AFTER MAIN-BATTERY DIRECTOR

The results obtained in the after main-battery director indicate that in this particular installation U.S. Rubber mounts are effective in

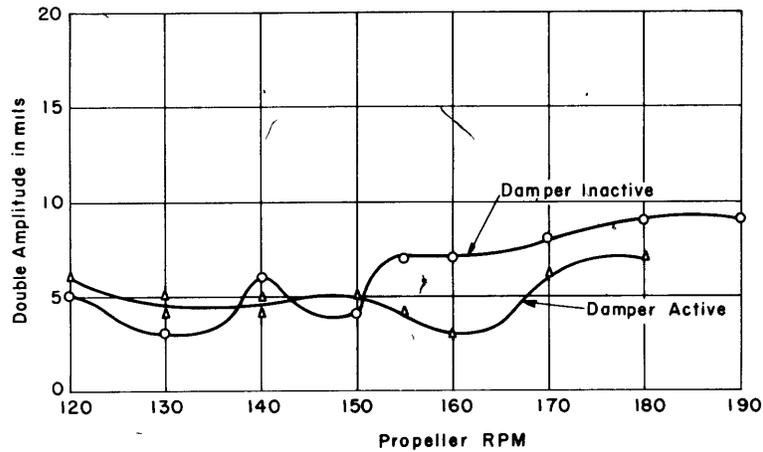


Figure 24a - Train Angle, 180 Degrees

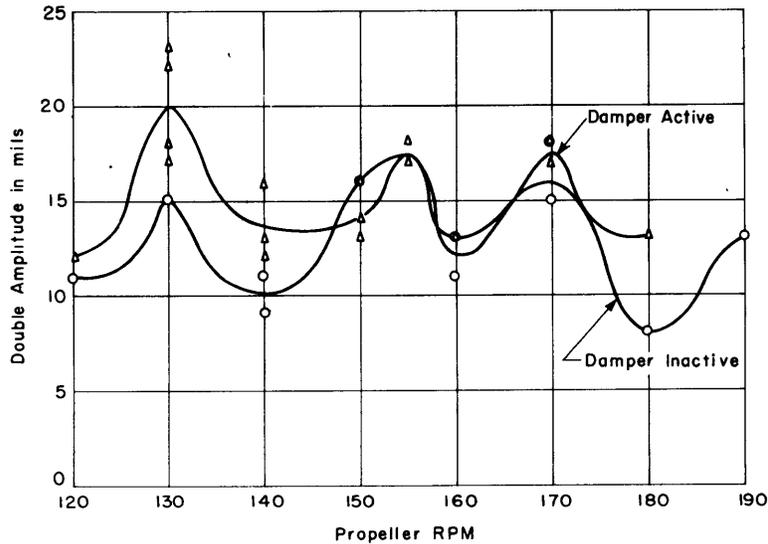


Figure 24b - Train Angle, 270 Degrees

**Figure 24 - Amplitudes of Horizontal Vibration
of After Secondary-Battery Director**

The vibration was measured parallel to the rangefinder axis.

reducing the amplitudes of vibration at the end of the rangefinder. This is readily seen by comparison of Figures 18a, 19a, and 22a with Figures 18b, 19b, and 22b; peak double amplitude of vertical vibration obtained with the rubber mounts active was 13 mils as compared with 56 mils with the rubber mounts and neutralizers both locked. The contrast in horizontal amplitudes is greater, the maximum double amplitude recorded being about 20 mils with the rubber mounts active (neglecting turns) and about 110 mils with the rubber mounts and neutralizers both locked. The effectiveness of the rubber mounts decreases during turns, a peak double amplitude of 38 mils being recorded during a turn.

Figures 22a and 22b, the curves showing vibration in the optical field, indicate the same general trends as the curves of rangefinder vibration, with some differences in detail. The performance of the rubber mounts, for certain conditions of steady vibration, is relatively superior to that of the neutralizers although the superiority of the rubber mounts over the neutralizers does not appear to be as pronounced as the tube-vibration data indicate. With the neutralizers properly controlled, i.e., locked when necessary, the maximum vibration in the optical field is about half that with the neutralizers locked throughout, and the amplitude at the critical speed, about 155 RPM, is reduced to about one-fourth its original magnitude.

As the neutralizers are intended to operate primarily at or about one speed, and are selectively controlled, it is essential that their performance be judged on the optimum conditions obtained with their use either locked or active, as conditions dictate. The curves of Figures 18 and 19, considered on this basis, give the following information:

a. At 90-degree train, use of the neutralizers reduces the maximum amplitude of vertical vibration at the end of the rangefinder by about 40 per cent. Double amplitude at 130 RPM, the critical speed, drops from 56 mils to 32 mils. Although a peak of 56 mils is obtained at 165 RPM with the neutralizers active, this peak is eliminated by locking the neutralizers.

b. At 180-degree train, the effectiveness of the neutralizers in the vertical direction appears to be considerably less than at 90-degree train. There is no significant reduction of amplitude at the critical speed of 130 RPM, although there is a 25 per cent reduction at the secondary critical speed of 165 RPM.

c. The neutralizers are more effective for horizontal vibration at the end of the rangefinder than for vertical vibration. At 90-degree train, although the peak double amplitude at 130 RPM is reduced only 20 per cent, from 50 mils to 40 mils, the amplitudes are diminished considerably between 140 and 170 RPM, maximum reduction being obtained at 155 RPM, where the amplitude is reduced about 90 per cent, from 40 mils to 4 mils.

d. At 180-degree train, the maximum double amplitude of horizontal vibration is decreased with the use of the neutralizer about 60 per cent, from 100 mils at 155 RPM, the critical speed, to about 40 mils. In addition, the neutralizers produce a general decrease in the vibration amplitude at higher speeds. The apparent large reduction in amplitude at 190 RPM may be regarded with some suspicion,

as the reported amplitude of 110 mils at 190 RPM with neutralizers locked is not supported by other evidence and may be incorrect.

From Figures 20 and 21, it appears that locking or activating the neutralizers or the rubber mounts produced no significant variation in the amplitudes of vibration at the bearing pedestal and at the end of the range-finder shield, although the amplitudes at the bearing pedestal were generally greater at 180-degree than at 90-degree train.

To obtain information for improvement of the neutralizer efficiency the following questions require investigation:

1. Why do the amplitude peaks obtained with the neutralizer active generally occur at about the same frequency as the peaks with the neutralizer locked, when theoretically the neutralization should be best at the critical frequency?

2. Why are the neutralizers more effective against horizontal vibration than against vertical vibration?

3. Why are the neutralizers less effective at 180-degree train than at 90-degree train?

The first two questions may best be answered by finding the answer to a more fundamental question: "What are the principal factors that may reduce the effectiveness of a vibration neutralizer?" These are:

1. The structure is not vibrating at its critical frequency. An undamped, tuned neutralizer is most effective at the critical frequency of the structure on which it is installed.

2. The natural frequency of the neutralizer is not the same as the critical frequency of the structure, i.e., the neutralizer is not properly tuned.

3. The forces and motions are not adequately transmitted between the neutralizer and the structure. This condition may obtain when the connection between the two is not sufficiently rigid.

4. The motion of the vibrating element of the neutralizer is impeded by friction or damping.

Application of these criteria to the manner of construction and mounting of the neutralizers indicates the most probable sources of ineffectiveness of the neutralizers. Clamping of the neutralizers to the ends of the rangefinder over the felt insulation probably prevents complete transmission of the forces, lowering the obtainable neutralization. The vibrating element of the neutralizer, not being guided, vibrates laterally as well as along the spring axis, often slapping against the frame of the neutralizer

and thereby introducing frictional restraint. Finally, it is possible that the neutralizers are not properly tuned to the critical frequencies of the rangefinder, in spite of careful preliminary testing. The superior performance of the horizontal neutralizer is probably due to smaller losses in efficiency from the three causes discussed.

As to why the neutralizers appear to be less effective at 180-degree train than at 90-degree train, the answer is not readily apparent. It is presumed that there may be more motion of the rangefinder parallel to its axis at 180-degree train than at 90-degree train. Such increased longitudinal vibration might cause more slapping of the vibrating element against the frame of the neutralizer, with consequent loss in effectiveness.

Possibly one of the most important factors preventing effective operation of the neutralizers is the absence of "steady-state" conditions of vibration during regular operation of the ship. The propellers are rarely all at the same speed, and generally do not remain at constant speed. Coupled with the fact that on the WASHINGTON both 4- and 5-bladed propellers were used on the outboard and inboard shafts respectively, and the port inboard shaft could not be run faster than 150 RPM, these variations caused a continually changing condition of vibration, characterized by beats and other variations of frequency and amplitude. The undamped neutralizer, particularly with a fairly small relative mass, is effective in a limited frequency range. It is possible, furthermore, that in the undamped neutralizer as used here the variations in amplitude tend to excite free oscillations of the vibrating element which affect the rangefinder.

It appears from the foregoing discussion that, if neutralizers are to be used successfully to combat vibration, they must incorporate, besides improved attachments to the vibrating structure and guides for the element, effectiveness over a wide range of frequencies. This can be achieved by a damped neutralizer, properly tuned, with a relatively high effective mass ratio. Such a device is now being developed at the Taylor Model Basin.

RANGEFINDER VIBRATION IN FORWARD MAIN-BATTERY DIRECTOR

The principal source of uncertainty about the possible effectiveness of dashpot dampers, before installation on shipboard, was the question of vibration of the protective shield around the rangefinder. The shield, which serves as a base for the dashpots, must be rigid relative to the rangefinder in order to provide the desired restraint. In addition, it is imperative that the shield does not vibrate excessively, i.e., resonate, in the frequency range encountered on the ship. If it did, it would transmit vibration through the dashpots to the rangefinder.

The data on the vibration of the rangefinder in the forward main-battery director, although limited in extent, indicate clearly the effectiveness of the dashpot dampers. Use of the dampers reduced the peak vertical amplitude of vibration to an average of one-third the amplitude obtained with the dampers inactive. Furthermore, no significant peaks were obtained with the dampers acting, whereas a definite critical frequency was obtained without the dampers. The application of the dampers in the forward main-battery director may well be termed successful.

Besides the direct evidence in the forward director of the effectiveness of the dashpot dampers in that installation, the vibration data concerning the shield of the after director indicate the probable success of a similar installation there. Practically all observed double amplitudes of vibration at that location were less than 10 mils, only four amplitudes exceeding that value, except during turns. The greatest double amplitude observed, except during turns, was 14 mils, and the maximum double amplitude observed during a turn was 19 mils. The small amplitudes observed and the absence of a resonant peak show that the shields would be fully adequate as a base for the dashpot dampers.

In view of the likelihood that the dashpots would serve effectively to damp out shock-induced vibrations, these devices appear to represent a satisfactory solution to the problem of vibration of the Mark 48 Rangefinder.

VIBRATION OF AFTER SECONDARY-BATTERY DIRECTOR

From Figure 24 it appears that the seismic damper caused no appreciable systematic change in the vibration of the after secondary-battery director during the sea trials. This is somewhat at variance with the results obtained in the preliminary tests with the vibration generator, which showed that the damper produced a reduction of about 30 per cent in the peak amplitude. As the effectiveness of the seismic damper is relatively independent of frequency, absence of a reduction in amplitude during the sea trials cannot be ascribed to variations in frequency. The reason for the difference in behavior is not readily apparent. It may be concluded, however, that a considerably larger weight than the 600 pounds used would be required to damp effectively the vibrations of the director.

One expedient that has been proposed and appears to warrant further consideration is to spring-mount the entire armored portion of the director (between limit stops, of course) and to use this as the seismic weight in either a seismic damper or a damped vibration neutralizer. The difference between the two lies principally in the tuning: the damper would have a natural frequency well below the range usually encountered in operation of the

ship, whereas the neutralizer would have a natural frequency somewhere around the critical frequency of the tower, depending on the usual factors (10).

CONCLUSIONS

On the basis of the foregoing material, the following conclusions are drawn:

1. The dashpot damper is effective in reducing the vibration of the Mark 48 Rangefinder, and may justifiably be expected to be effective against shock-excited vibrations. If the shields are to be retained around the Mark 48 Rangefinder, this device, if installed, would undoubtedly improve ranging conditions under vibration. Even if shields are not retained, the dashpot dampers could probably be used effectively when supported by a light, rigid framework built up from the director.
2. The U.S. Rubber mounts installed in the WASHINGTON appear to be effective in reducing propeller-excited vibrations of the Mark 48 Rangefinder. No evidence was obtained about action of these mounts or the other antivibration devices tested under shock excitation on shipboard.
3. The Mark 48 Rangefinder vibration neutralizers, selectively controlled, are in general beneficial, reducing the peak vibration amplitudes to a certain extent. They are not, however, sufficiently effective in their present form to warrant any further installations on shipboard.
4. A set of hydraulically damped neutralizers for the rangefinder, based on the present neutralizer design but with about 5 times the effective mass, would be both feasible and probably sufficiently effective for all practical purposes. The Taylor Model Basin is currently engaged in the development of such devices for use on the Mark 48 Rangefinder.
5. The director vibration neutralizer, either in its original form or as modified to a seismic damper, is not appreciably effective in reducing director vibration. Development of a neutralizer or damper utilizing the armored portion of the director as the suspended weight moving between rigid stops might prove feasible and would probably reduce vibration considerably.

RECOMMENDATIONS

1. The dashpot dampers are recommended for installation on Mark 48 Rangefinders where excessive vibration interferes with effective use of the rangefinder, if the shields are retained around this rangefinder.
2. It is recommended that consideration be given to the use of dashpot dampers on other rangefinders surrounded by shields, providing the shields do not vibrate excessively within the frequency range encountered on shipboard.

3. It is recommended that further work on elimination of rangefinder vibration center on the following antivibration devices for use on rangefinders without shields:

a. A light, rigid structure, not too unsightly, for supporting a dashpot damper at the end of the rangefinder;

b. A dashpot damper installed inside the director, probably at the midlength of the rangefinder;

c. Damped neutralizers, based on the design of the neutralizers discussed here, embodying a heavier, guided element, oil damping, and a more rigid attachment to the rangefinder; these are currently being developed at the Taylor Model Basin.

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