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# **SHOCK AND VIBRATION BULLETIN**



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## FOREWORD

A Centralized Navy Shock and Vibration Scientific Unit was established last December. Since then, four technical symposia have been conducted in the Washington area. About fifteen Naval activities, as well as other Government agencies, participated in the discussions and inspected the facilities of the various laboratories. All groups are now aware of the possibilities and the existing tools for attacking problems in shock and vibration.

The next step planned by the Agenda Committee is an examination of the diverse technical approaches leading to effective solutions of these problems. With this perspective in mind, a series of topics (see SAVIBULL) have been scheduled for review and discussion. The symposia programs for 1947 should outline the broad areas of research and development in this field, and point the way to fruitful and cooperative effort.

During the past formative months, the Centralizing Group has been stimulated and encouraged by the splendid cooperation and wholehearted support of all participating activities. The same interest and zeal at the coming symposia will assure achievement of our goal, namely: *To develop methods and means for the protection of vehicles, personnel, and equipments associated with the Fleet.*

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THE THIRD SYMPOSIUM  
Naval Ordnance Laboratory  
19 March 1947

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Mr. N. H. Jasper  
Comdr. A. O. Doritz  
Mr. F. F. Vane  
Mr. D. Smith

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Mr. C. M. Ryerson  
Mr. J. P. Strong  
Mr. J. J. Peirano  
Mr. A. Leventhal  
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Mr. F. A. Ross  
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Mr. F. L. Havercroft  
Dr. Elias Klein  
Mr. I. L. Chevrick  
Mr. F. Bird  
Mr. P. Delisi  
Mr. J. M. Taylor  
Mrs. J. B. Green

## SUMMARY

The third meeting of the Shock and Vibration Symposium was held at the Naval Ordnance Laboratory, Naval Gun Factory, on 19 March 1947.

The morning session was devoted to a discussion of NOL's shock and vibration equipment and a guided inspection tour of the installations.

Three talks were presented during the afternoon: *Evaluation of Inertia-Operated Devices*, by J. H. Armstrong (NCL); *History and Development of the Lightweight Class-HI Shock Machine*, by R. H. Oliver (BuShips); and *Applications of the Lightweight Shock Machine*, by W. H. Hoppmann (New York Naval Shipyard).

## INTRODUCTORY REMARKS

Capt. F. S. Withington, NCL

On behalf of the Bureau of Ordnance, I am glad to welcome you all to the Naval Ordnance Laboratory. We think here that technical symposia such as these should result in great benefit to the entire naval establishment.

At the Naval Ordnance Laboratory, we are interested in shock phenomena for a variety of reasons. We are conducting basic research in the shock phenomena resulting from chemical explosions. We must design weapons capable of withstanding heavy impact shocks. We must test all of our designs for shock resistant qualities, and use Laboratory facilities

to a maximum in order to reduce the cost of full size test vehicles.

We must not only design mechanisms capable of withstanding shock, we must also design mechanisms such as contact torpedo exploders which depend upon impact shock for their activation.

The Laboratory facilities at White Oak will include many facilities for Laboratory analysis and simulation of shock and vibration. The shock vibration test equipment which you will see today has given important service in the development of weapons. Space here is small and cramped but the work can and does go on.

# THE HISTORY AND DEVELOPMENT OF THE HIGH-IMPACT SHOCK-TESTING MACHINE FOR LIGHTWEIGHT EQUIPMENT

R. H. Oliver BuShips

Until such time as our committee on definitions comes forth with a suitable definition of the term *shock*, I am forced to refer to shock in the same loose vein as in the past. On this basis, shock has been generally thought of as that phenomenon which is characterized by the rapid initial displacement of a foundation or structure, followed by a violent, transient, decaying vibration of the foundation or structure at its own natural frequency or frequencies of vibration. In the event that the shock is not confined to a single pulse, but

has several pulses, as is the case with underwater explosions at considerable depth, the initial displacement may be amplified in the succeeding violent vibration or may be nullified, depending on the shock pulse frequency, the natural frequency of vibration of the foundation or structure, and the phase relationship between them.

At the close of World War I, and even up to the early part of the year 1939, the major causes of shock to equipment aboard vessels of the U. S. Navy were

considered to be impacts from enemy shells and torpedoes and the firing of the ship's own armament. At that time it was generally conceived that nothing much could be done about equipment which was subject to shock from enemy causes other than to avoid, if possible, the mounting of equipment directly on armor plating.

Insofar as shock to equipment caused by firing the ship's own armament was concerned, it was generally agreed that equipment mounted in the main-battery turrets, broadside-gun compartments, and the like needed to be more ruggedly constructed. Requirements for ruggedness of reduced magnitude were also found to be necessary in other portions of the ships which were observed to transmit shocks to equipment. In order to be able to test equipment for these various requirements, the shock-testing machine, now commonly known as the 150- or 250-foot-pound machine, was devised and constructed shortly after the close of World War I. The machine was so arranged as to test for the requirements of 25, 50, 150, and later 250 foot-pounds, which were imposed on equipments for various locations in the ships. Equipment passing these tests was considered satisfactory for installation aboard ship.

The deficiencies of cast iron and other brittle materials for use in equipments aboard ship were recognized, and, insofar as possible, steps were taken in the late 1930's to eliminate their use for strength members of equipment, especially the use of cast iron in end bells on motors and generators. This was the only major change made in design to evolve equipment which was more resistant to shock.

The early stages of World War II brought great changes in the problem of protecting equipment from shock aboard ship. Influence mines, containing large charges of explosive, and large aerial

bombs were being used. It was found through bitter experience that near-miss aerial bombs exploding below the water surface and non-contact explosions of mines were giving the ship as a whole a terrific shaking without necessarily causing major hull damage. Equipment mounted on decks and bulkheads disintegrated; heavy machinery items came adrift because of failure of the mounting feet; piping and ventilation systems throughout the ship were demolished. The need for better equipment and mounting methods was imperative.

As a method of approach to solving the problems involved, the British designed a machine in 1939 which is very similar to our present machine for testing lightweight equipment. It was believed that the shocks administered by this machine were closely similar to those encountered aboard ship, because damage inflicted on equipment tested on the machine was very similar to that observed on identical units of equipment mounted aboard ship.

Late in 1940, the General Electric Company manufactured one machine from British sketches for use in this country. After considerable experimental testing was performed on this machine, it was considered that it would be an invaluable aid to our Navy in the design of shock-proof equipment. Accordingly, a contract was entered into with General Electric to furnish machines for use in the Navy Yards in New York, Portsmouth, and Washington, and at the Naval Research Laboratory. By late 1942, several private concerns, including General Electric, Westinghouse, ITE, Cutler-Hammer, Allis-Chalmers, Ward Leonard, and the Arma Corporation had arrived at the conclusion that a machine in their own plants was indispensable. Machines were purchased and put in operation in the plants of these various manufacturers.

Also late in 1942, a group of 16 manufacturing concerns in the Chicago area had realized the necessity of a machine for their use. Consequently these 16 firms put up sufficient funds to purchase one machine, which was installed at the Armour Research Laboratories in Chicago. It was considered advisable to establish the machine at Armour to preclude the possibility of one manufacturer's being required to test the products of other manufacturers. The Armour machine was completed and ready to conduct tests by mid-March of 1943.

The list of lightweight machines available for test purposes grew in this manner until, at the end of the War, a total of 25 were in operation. Of this total, eight machines were maintained in government laboratories.

In order to simulate on the shock-testing machine the various types of equipment-mounting conditions encountered aboard ship, a series of adapter plates for the machine were designed. The simple flat plate mounted out from the face of the anvil plate on car-building channels was thought to reproduce closely the action encountered by equipment mounted on bulkheads. A similar flat plate with a bracket or shelf protruding at right angles was constructed for equipment which is normally mounted on light decks or on brackets supported by bulkhead stiffeners. Other types of adapters were designed to provide mountings for switchboard instruments and the like, which were quite similar to the types of mountings found aboard ship for these particular equipments. It is to be kept in mind that all of these adapters were designed for testing equipment whose weight was not in excess of approximately 250 pounds.

The continued operation of these machines brought to light several deficiencies in their design. The first

major trouble encountered was mechanical failure of the anvil plate after a considerable number of blows had been administered. The stiffeners on the backs of the plates broke, and failure of the intermittent weld holding the stiffeners was encountered. As a result of these failures, the anvil plates dished and warped. Consequently the anvil plates were redesigned using 13.8-pound H-beams for stiffeners in place of the original T-beams, and continuous fillet welding was employed. In addition, an extra plate was introduced between the striking pad for the back blow and the H-beam structure, to allow better stress distribution.

These changes in the design of the anvil plate resulted in a great improvement in the useful life of the plate. However, it was soon necessary to change again the design of the plates to conform with the rulings of the War Production Board. The Board deleted the 13.8-pound H-beams from the list of shapes to be rolled, so redesign was effected to incorporate the use of 13.0-pound H-beams. For the sake of uniformity among machines, all owners were requested to install anvil plates incorporating the lighter beams for stiffeners late in 1943.

Considerable trouble was also experienced in the maintenance of the bearings on the swinging hammer for back blows. The bushings were wearing to an oval shape in short order, and this wear caused the hammer velocity to be erratic. In addition, the arms supporting the hammer were not sufficiently rigid, and allowed the hammer to wobble so that the striking pad of the anvil plate was not struck squarely. These difficulties were overcome by stiffening the arms and installing longer bushings at the pivot points.

A series of high-speed movie shots were taken of one of the unmodified

machines at the Naval Research Laboratory. This film shows quite plainly the action of the machine at the instant of impact for all three directions of hammer blow. It shows considerable rocking of the dropping hammer due to the flat contact surface of the hammer and the considerable amount of looseness in the hammer-guide tracks. Furthermore, by observing closely, it can be seen that the anvil plate does not return to its original position after the blow is administered.

It is apparent from this film that the shock administered to equipment mounted for test on the machine is of a very complex nature. This is in definite contrast to the type of shock administered by the various machines which were viewed at NOL. These machines imparted shocks of a very simple nature, such as a sine-wave pulse, a square wave, and the like. The shocks encountered by equipment aboard ship are of a complex nature, and the HI shock machine intentionally imparts a complicated shock motion to equipment.

Very early in 1943, as the number of **these** machines in operation increased, it became apparent that there were numerous discrepancies between the various machines, which affected the nature and intensity of the shocks administered. The fact that equipment which had passed all developmental testing on a manufacturer's machine sometimes failed to pass the acceptance tests on a government-owned machine particularly indicated the existence of these discrepancies. Furthermore, it was readily apparent that the intensity of the shocks was not identical in all three directions of blow on any of the machines.

Consequently, in May of 1943, a broad program was authorized to investigate the operating characteristics of all machines for the purpose of standardization, so that the severity of test would be identical for all three

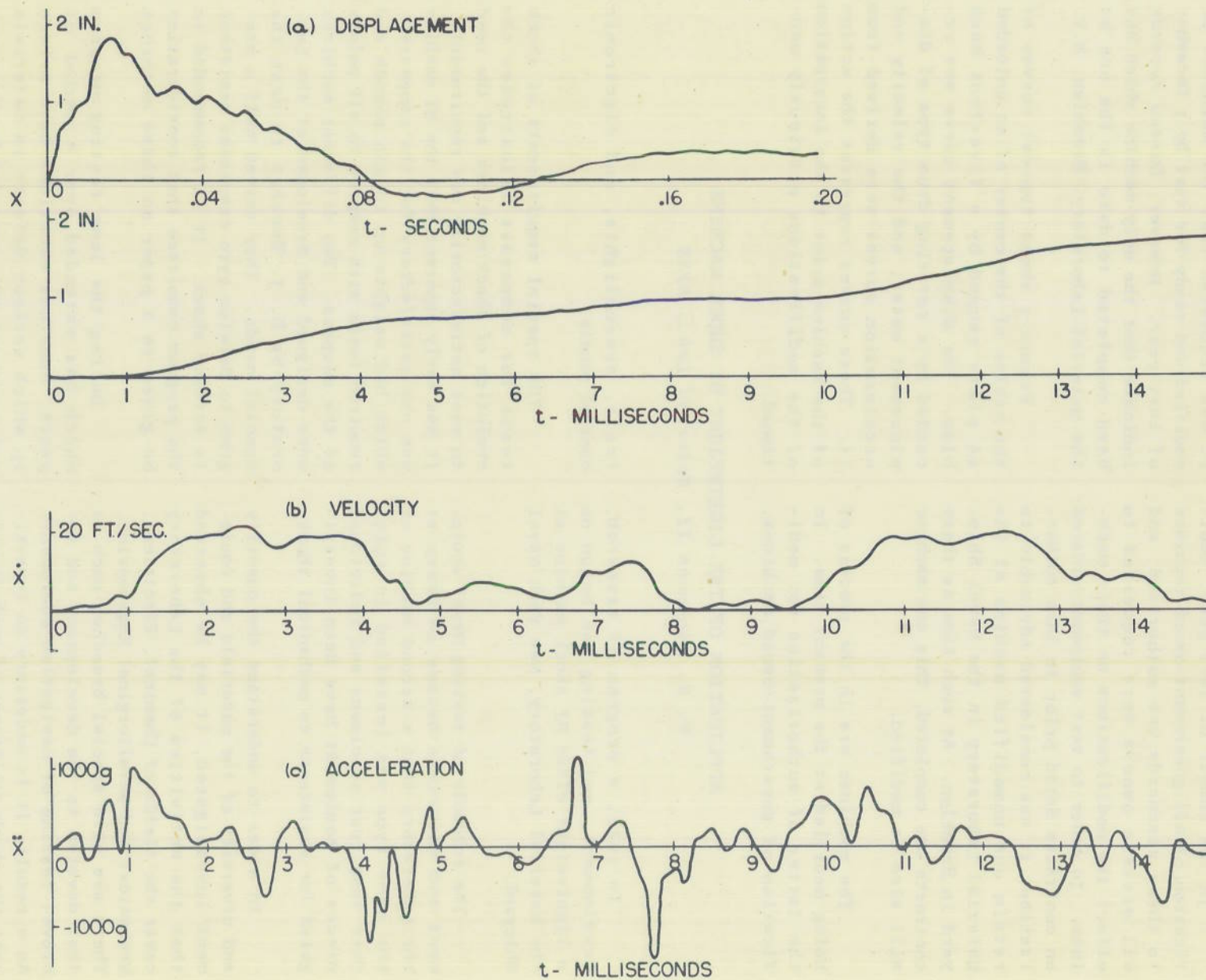
directions of blow, and would be the same on all the machines. The revolving-drum type of displacement recorder was considered at that time to give the most faithful reproduction of the action of the machines, in addition to being one of the most simple of the available instruments to operate. The action of a considerable number of the machines was investigated and recorded for all directions of blow, and for several intensities of blow with various loads on the 4A adapter plate.

Comparison and analysis of all these records led to a series of modifications which were effected on one of the machines at the Naval Research Laboratory. Extensive tests were made on the modified machine, and the records taken were compared with those which had been taken previously on the other machines. It was considered that, as a result of these modifications, the severity of test was closely the same in all three directions, and that the nature of the modifications would assure close similarity of test on all machines. Conclusions and recommendations regarding the modifications were put out in report form by the Naval Research Laboratory late in 1945.

The major changes to be made were:

1. Installation of hammers having approximately spherical contact surfaces.
2. Replacement of the swinging-hammer arms by new ones which had more rigidity and greater width of suspension, to eliminate wobbling of the hammer laterally as it falls.
3. Replacement of the lorry springs beneath the anvil plate by coil springs having stops to limit the travel to  $1\frac{1}{2}$  inches.
4. Installation of positive stops on the springs retarding the motion of the anvil plate under the action of back and side blows. These stops limit the travel to  $1\frac{1}{2}$  inches.

FIG. 1. Characteristic curves for HI Shock Machine



In the summer of last year, modification of all government-owned machines to these standards was authorized, and all private owners were requested to effect the modifications on their machines. In order to test equipment ordered on contracts dated prior to this authorization, it was considered advisable to retain one unmodified machine at the Material Laboratory in the Naval Shipyard in Brooklyn. At such time as these contracts are completed, this one machine will also be modified.

The machines are in the process of being modified at the present time. In the letter of authorization for modification of government-owned machines,

it was requested that the machines be modified and ready for test by 1 December of last year. However, Bureau records indicate that the only machine which has been completed to date is the one at the Material Laboratory, Brooklyn, N.Y.

Figure 1 shows typical curves of the action of the center of an unloaded 4A plate caused by a five-foot back blow. The displacement curve was recorded by a rotating drum type of displacement meter, and the velocity and acceleration curves were derived from it. These curves represent the action of the machine prior to the incorporation of the modifications previously mentioned.

#### APPLICATION OF THE LIGHTWEIGHT HI SHOCK MACHINE

*W. H. Hoppmann II, Material Lab., NYNS*

In 1941, a program of research, development, and testing was begun on a lightweight class HI shock machine at the Material Laboratory, New York Naval Shipyard.

The schedule of testing Naval equipment and materials became so heavy at the Laboratory that a second machine of the same type was installed in 1945. Over 7000 test specimens and individual pieces of equipment have been investigated for resistance to mechanical shock.

In order to understand the quantity and diversity of the materials and equipment investigated, it may be observed that the activities of the Laboratory cover the fields of Chemical, Electrical, Mechanical and Metallurgical Engineering. There are also special branches such as that devoted to the development and approval testing of navigation equipment. As a result, it is necessary to investigate the shock resistance of such diverse items as voltmeters, switches, wet-cell batteries, gyro compasses, ventilation fans, plastic devices, thermostatic con-

trols, searchlights, and electronic control panels.

The special requirements of shock tests for compasses illustrates the evolution of shock machines and the need to meet satisfactorily new requirements. It was early apparent that the HI machine was not satisfactory for the compasses, which had weights up to 800 pounds and required tests with respect to all points of the compass. Two different machines were designed and developed at the Laboratory by B. J. Baecher to meet the special needs. They served well a program to develop gyro compasses resistant to service shock. It is recommended to the program committee that consideration be given to a paper on these machines.

During the long testing program which has extended over a period of years, numerous occasions have arisen in which serious defects in materials and equipment were revealed by the shock test and eliminated by subsequent development. As an example, reference may be made to a small axial-flow ventilation

fan that was tested only a few weeks ago. In the course of a test on the HI machine, a circumferential crack developed in the casting which formed a housing for the air impeller. Radiographic analysis revealed that this crack corresponds to a circular path of porosity in the casting. The radiograph also revealed a similar line of porosity on the opposite end of the housing which probably would also crack. Here we have an example of the detection of a flaw not apparent by simple visual observation. Such a use of the machine leads to the development of better equipment for Naval use.

Any activity with a shock machine and development engineers experienced in structural resistance to shock is in a position to make its products more shock resistant. In the case of the fan just mentioned, all that is needed is a sound casting.

Hand-in-hand with the development of shock-resistant equipment goes the development of shock-testing machines. The Bureau of Ships has underway a program for improving the lightweight HI shock machine. The plan is to make the action of the machine as nearly the same as is practicable in the three principal directions--rear, vertical, and sidewise. For the purpose, the carriage-type leaf springs used in vertical shock are dis-

carded. Compression-type coil springs, housed in steel cylinders with the spring extending in a free condition a prescribed distance beyond the free end of the cylinder, are used. Also, the striking surfaces of the hammers have been altered to provide more uniform and reproducible test conditions. It is the intention of the Bureau to determine experimentally the action of the machines after the alterations. At present, one machine at the Laboratory has been modified as directed. The other machine is unaltered in order to test equipment purchased according to the old specifications.

Some research and development work has been carried out at the Material Laboratory on the HI shock machines. Response of structural elements have been studied, measuring instruments have been developed, and devices for testing materials in simple tension, shear, and bending have been designed, built and tested.

With regard to the testing of all of the equipment at the Material Laboratory, acknowledgement is made of the efforts of the engineers with cognizance of the various kinds of material and equipment, but special mention is made of the work of development and testing on the HI shock machine by E. C. Taylor.

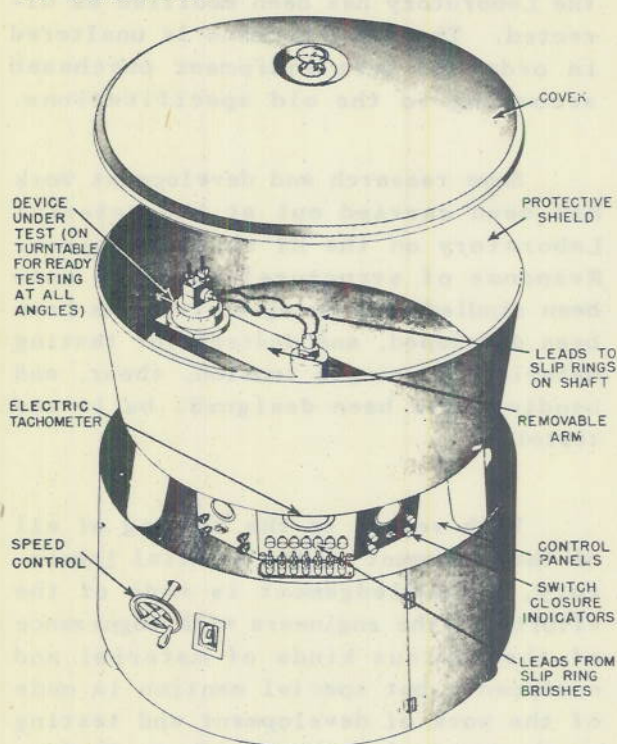
#### DEVELOPMENT OF NOL SHOCK AND VIBRATION TESTING EQUIPMENT

Prior to the wartime expansion of the types of weapon designed by the Naval Ordnance Laboratory, the Laboratory's requirements for shock and vibration facilities were confined to those of the Mine Test Organization. Further limitation of these requirements occurred because mines at that time were generally of the moored contact type that had been developed over many years by empirical methods. The principal shock problem for which simulation facilities were then required was that of possible damage to

rather rugged mine structures by the relatively small forces associated with launching from a ship.

In 1941, the Mine Test Section constructed a ten-foot drop tester that is still in existence between Naval Gun Factory Buildings 210 and 172. In spite of the limitations in the shock effects that it could produce, this drop tester was used to test individual mine components that were then being designed for use in new air-craft-launched magnetic mines,

At about the same time, a 24-in. arm horizontal-axis centrifuge was put into use. The centrifuge allowed the steady building up of forces proportional to mass and, therefore, similar in distribution to inertia forces. These forces were applied to delicate parts until failure occurred. This procedure indicated the weakest parts of complex mechanisms and determined their static strength, but dynamic effects could not be simulated.



Low-speed centrifuge, Type 2-A

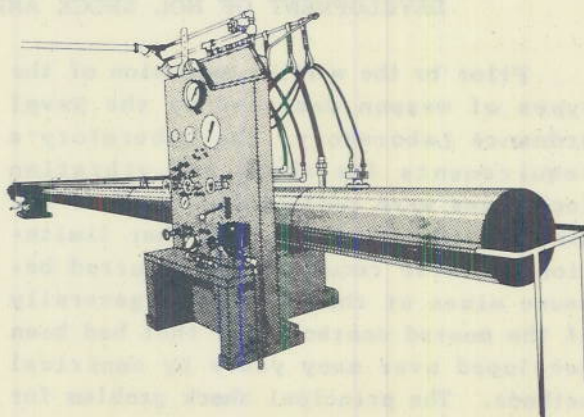
The concentration of interest on new magnetic mines also led to consideration of the damage to such delicate devices as sensitrol relays and firing mechanism gimbals by vibration occurring during various types of transportation. The first NOL vibration simulator was built in 1942 and was of the vertical-amplitude reaction-driven type. It could accommodate only small components weighing about thirty pounds or less. Complete mines, including the anchor that serves as a carriage for the case, could be vibrated on a section of launcher track

that was set up so that it could be activated by the same small vibrator drive. To obtain sufficient amplitude, the track was clamped at both ends and the length of the span was adjusted so that the system could be driven at resonance.

As the mine development program continued, aircraft launching conditions became more severe and the fact that field tests had to be performed at remote stations emphasized the desirability of establishing valid laboratory simulation methods that would bring as much as possible of the shock test work into the laboratory.

#### AIR-GUN DEVELOPMENT

Analysis of the limitations of the drop tester and centrifuge types of equipment made it apparent that the total energy available in any practicable drop tester would be inadequate for the simulation of the water-entry shocks received by a mine. Also, it was apparent that the maximum rate of application of acceleration by any practicable centrifuge could not be made adequate. Even though the Laboratory had developed techniques for varying the duration of drop-tester shocks, the total available energy was so low that useful accelerations could not be maintained for periods long enough to test for effects such as internal collisions between components.



Shock-testing air gun (15")

A theoretical study was made of possible methods of storing enough energy for the production of high-acceleration long-duration shocks. The use of gravitational potential energy required a structure of excessive height and, therefore, was abandoned. The use of stretched rubber as a source of energy was considered, and a machine was designed in which rubber shock cords increased the downward acceleration of the carriage. Disadvantages of this design were that the magnitude of the initial downward acceleration was so great as to complicate the interpretation of results, and the engineering use of rubber at that time was insufficiently developed. The principle of storing energy in the form of compressed air was considered. Methods based on this principle appeared to offer the best prospects.

A machine that later became known as an air gun was designed on the compressed-air energy storage principle. In the first and all subsequent air guns, the mechanism under test is carried inside a cylindrical piston. The piston is a free fit in a long tube that resembles a gun barrel. The piston is held by a mechanical clamp while air pressure is built up in the "breech" until energy sufficient to accelerate the piston at the desired rate and for the desired time is attained. The piston then is released suddenly and travels down the tube in front of the expanding air. Energies of the order of 200 times those available at equivalent accelerations in the drop testers are obtained by this method. The first gun had a 5.6-in. bore. It was completed in late 1942 and is still in use.

This first gun realized all the anticipated performance features. Its success led to the design and construction in 1943 of a 15-in. bore version.

The suitability of this type of equipment for laboratory investigations was soon demonstrated in the study of

cushions for mine mechanisms. Before the shock tests, there were conflicting views about cushioning that could not be resolved by theoretical studies. The 15-in. air gun was able to demonstrate with considerable precision the conditions under which various degrees of resilience could or could not be used in the design of mountings for delicate components.

The Laboratory's experience with shock equipment based on the compressed-air principle has been so favorable that extension of the scope of this equipment has continued. Present development in the air-gun field includes construction of a 21-in. bore machine, capable of accelerating the larger components of mines and torpedoes and of providing independent control over the various parameters of the acceleration-time curve.

#### VIBRATION TESTING

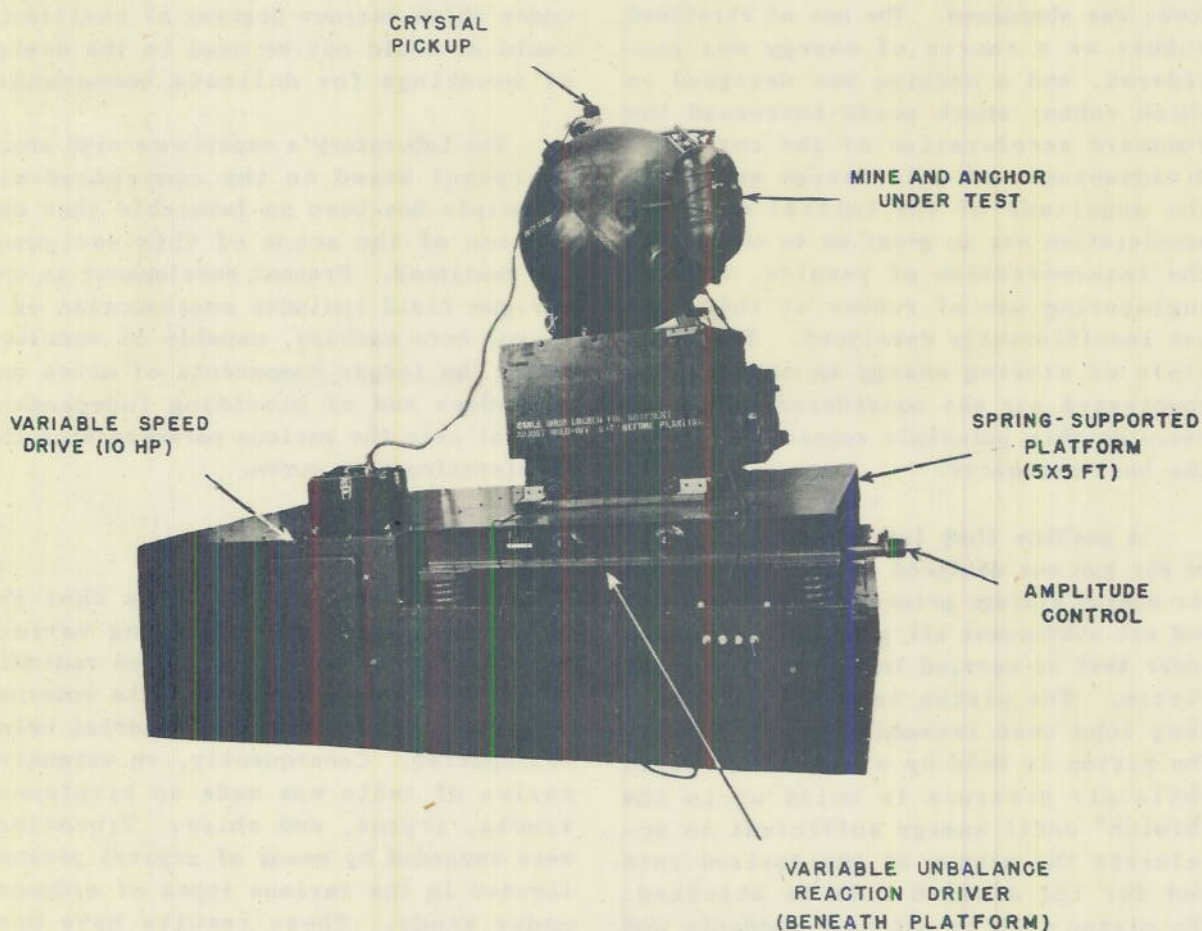
It was recognized early that the vibrations encountered during various modes of transportation might be radically modified when they reached the internal components of the ordnance material being transported. Consequently, an extensive series of tests was made on airplanes, trucks, trains, and ships. Vibrations were recorded by means of crystal pickups located in the various types of ordnance under study. These results have been used in setting up standard transportation and service vibration test programs.

In the development of vibration equipment, the Laboratory followed the policy of obtaining the best types of commercial equipment and of simultaneously developing NOL designed and built equipment that was able to provide performance unobtainable from the commercial models. In addition to developing the equipment and jigs appropriate to transportation-vibration testing of ammunition and mine components, facilities were established for determining the operability of many types of electrical and chem-

ical devices during the actual vibration period.

Another aspect of the evolution of vibration simulation was that several instances of alarming resonance phenom-

ena in elastic parts of certain components were discovered. The search for such resonance conditions became an established part of the Laboratory's ordnance development programs.



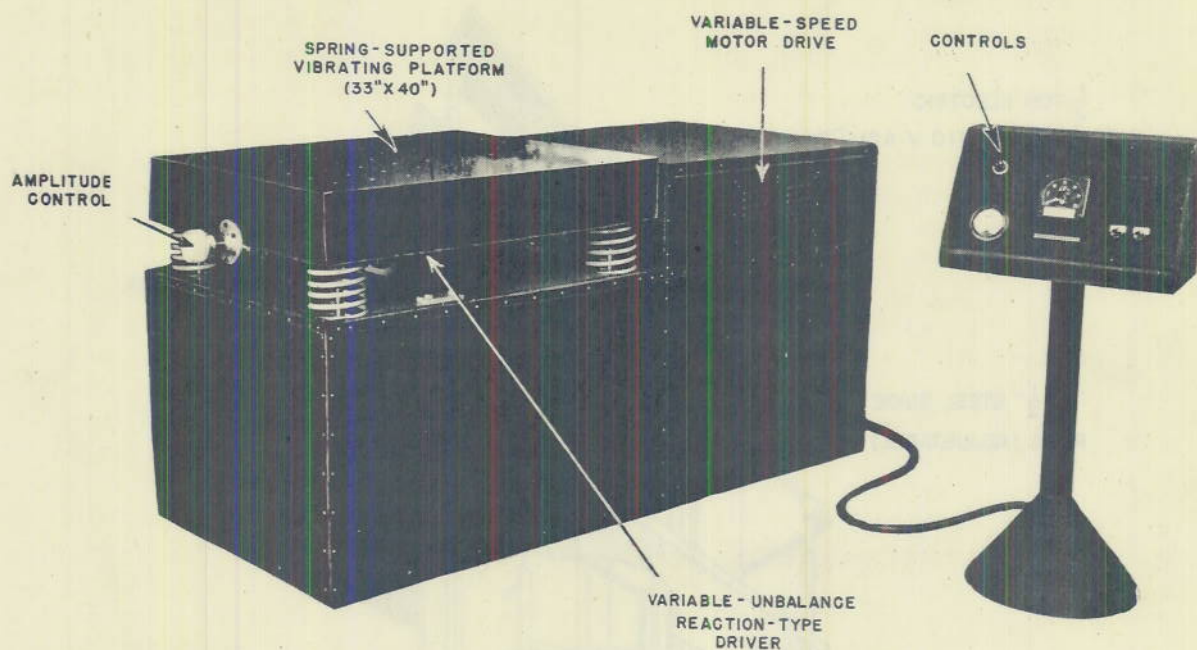
Vibrator Type 1-B

In 1944, machines capable of vibrating complete mines or torpedoes weighing up to 3000 pounds were completed, and facilities for performing extensive vibration tests at high and low temperatures have since been developed. The NOL equipment, designed especially for 24-hour cycle service, is all of the reaction-driven type. This has proved more reliable than the usual commercially available types of cam-driven machines.

Laboratory requirements of measuring resonance effects, of controlling con-

ditions in standardized testing, and of evaluating vibration-reduction systems in ordnance devices have necessitated acquisition and development of a wide variety of vibration-measuring instruments and techniques.

Investigations and tests in the high-frequency vibration range up to 20,000 cps can now be made with recently acquired commercial electromagnetic-drive equipment and NOL-built adaptations of this drive.



Vibrator Type 2-A

#### AMMUNITION TESTING

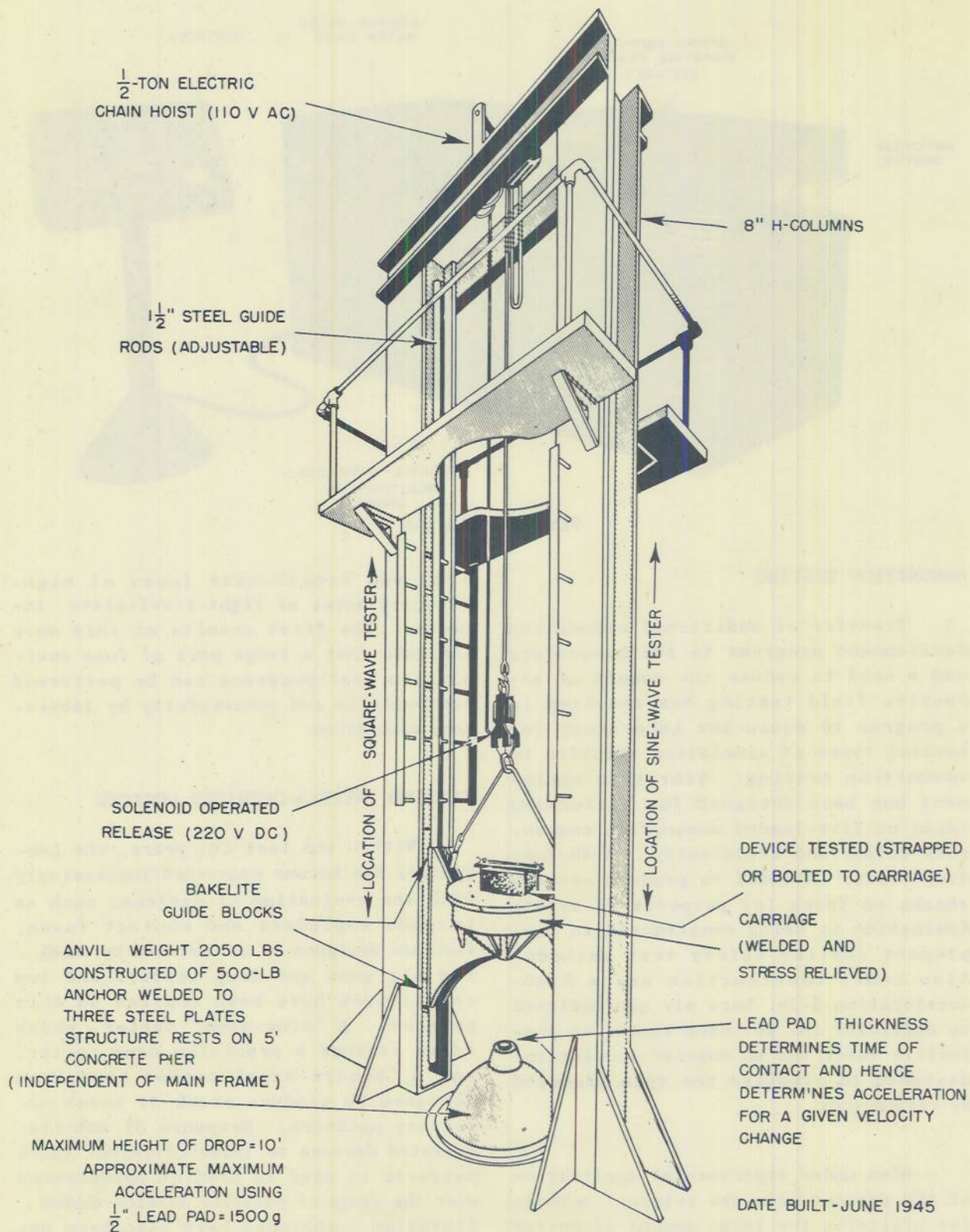
Transfer of additional ammunition development programs to the Laboratory and a need to reduce the amount of expensive field testing has resulted in a program to equip the Laboratory for several types of simulation specific to ammunition testing. Vibration equipment has been designed for performing tests on live-loaded ammunition components safely and efficiently. A 40-foot drop tester intended to produce extreme shocks on fuzes for purposes of safety evaluation is being constructed to supplement earlier safety test methods. Also under construction are a high-acceleration 5-in. bore air gun designed to duplicate the set-back shocks on projectile fuzes, and an angular accelerator designed to simulate the spin produced by rifled guns.

Also under experimental application at the present time are original methods for utilizing the large amount of energy available in the air guns for simulating in the laboratory the impact effects on

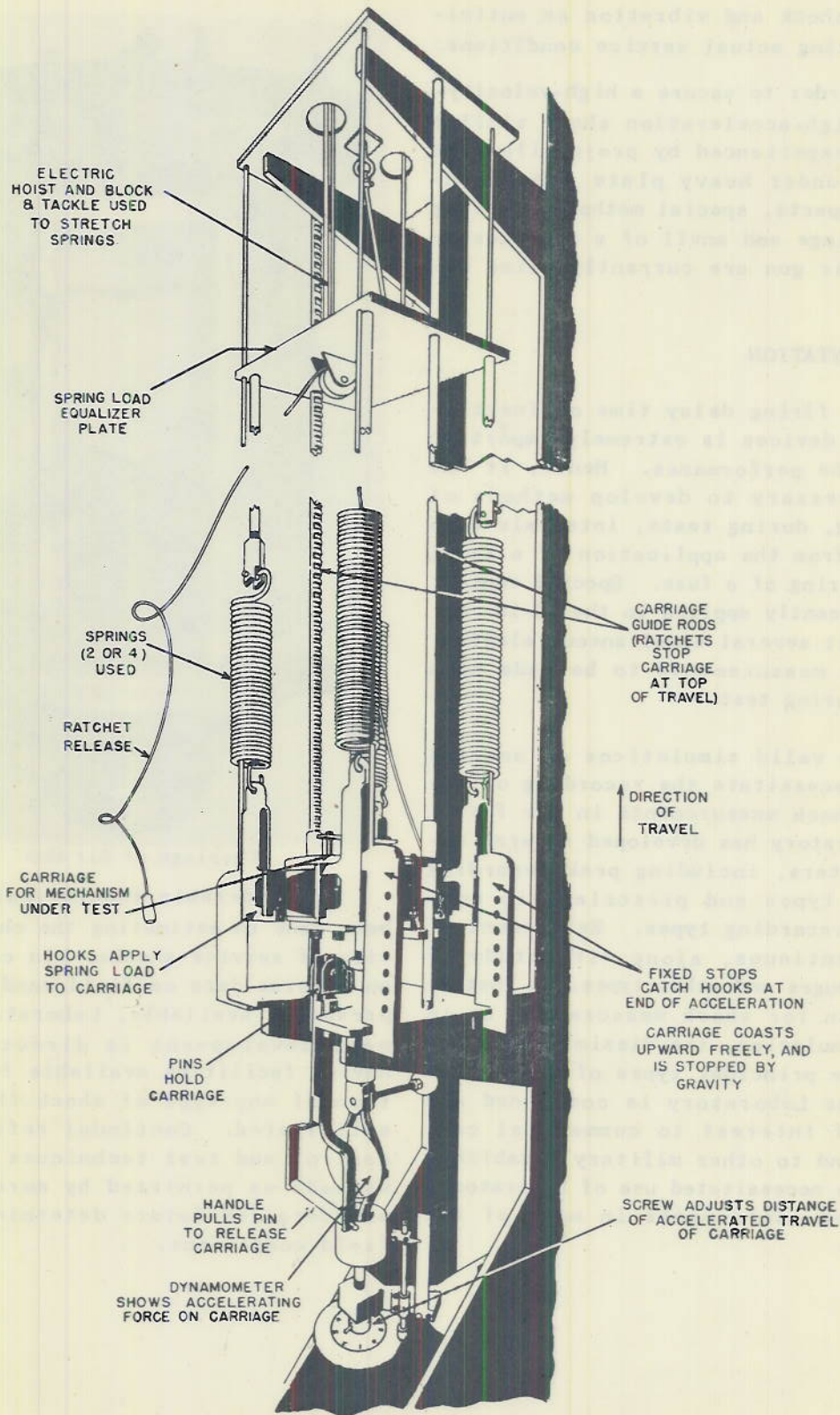
bomb and rocket-nose fuzes of high-velocity water or light-steel-plate impacts. The first results of this work indicate that a large part of fuze evaluation test programs can be performed economically and successfully by laboratory simulation.

#### TESTING INERTIA-OPERATED DEVICES

Within the last two years, the Laboratory has become concerned increasingly with the evaluation of devices, such as torpedo exploders and contact fuzes, that are designed to be operated by shock. The air guns and drop testers and two centrifuges have been applied to this purpose. A "sine-wave" tester, which is in essence a precision drop tester, and a "square-wave" tester have been designed to produce shock of known arbitrary patterns. Response of inertia-operated devices to these different shock patterns is used to predict performance over the range of possible service shocks. Vibration techniques have also been developed as necessary to permit testing such devices under the combined influ-



Drop tester (10 ft) Type 2-A



Shock tester, square-wave type

ence of shock and vibration as anticipated during actual service conditions.

In order to secure a high-velocity-change high-acceleration shock similar to that experienced by projectiles and rockets under heavy plate and earth-target impacts, special methods of using the carriage and anvil of a drop tester in the air gun are currently being developed.

#### INSTRUMENTATION

The firing delay time of inertia-operated devices is extremely important in service performance. Hence, it has been necessary to develop methods of recording, during tests, intervals such as that from the application of a shock to the firing of a fuze. Special contact strips recently applied to the 15-in. air gun permit several simultaneous electrical time measurements to be made on a device during test.

The valid simulations of service shocks necessitate the recording of accurate shock measurements in the field. The Laboratory has developed several accelerometers, including peak-recording crusher types and piezoelectric continuous-recording types. Refinement of these continues, along with study of strain-gauges and other types. In instrumentation for shock measurement as in shock simulation, the dissimilarity between the principal types of shock with which the Laboratory is concerned and those of interest to commercial companies and to other military establishments has necessitated use of Laboratory-developed instruments in most of the work.



Carriage of Air Gun

Considerable theoretical work has been done in estimating the characteristics of service shocks. In cases where no precise data on field conditions are presently available, Laboratory equipment development is directed toward having facilities available for simulation of any type of shock that may be anticipated. Continual refinement in control and test techniques then will be made as permitted by more accurate and detailed future determinations of field conditions.

# NOL VIBRATION TEST EQUIPMENT

| Type of Drive | Frequency Range (cps) | Maximum Acceleration (g) | Static Load Capacity (lbs) | Table Dimensions (ins) | Maximum Displacement (ins) | Table Movement | Manufacturer             |
|---------------|-----------------------|--------------------------|----------------------------|------------------------|----------------------------|----------------|--------------------------|
| Positive      | 8 - 50                | 8                        | 50                         | 13 x 17                | 0.063                      | Tridirectional | Vibration Specialty Co.  |
| Positive      | 8 - 50                | 8                        | 20                         | 13 x 15                | 0.063                      | Tridirectional | Vibration Specialty Co.  |
| Positive      | 18 - 100              | 23                       | 100                        | 15 x 18                | 0.125                      | Horizontal     | All-American Tool Co.    |
| Reaction      | 8 - 83                | 15                       | 30                         | 20 x 20                | 0.063                      | Vertical       | NOL                      |
| Positive      | 10 - 100              | 10                       | 100                        | 24 x 30                | 0.250                      | Tridirectional | L.A.B. Corp.             |
| Voice coil    | 10 - 10,000           | 140                      | 250                        | 7 x 10                 | 0.250                      | Vertical       | Westinghouse             |
| Reaction      | 8 - 50                | 10                       | 2500                       | 60 x 60                | 0.063                      | Vertical       | NOL                      |
| Reaction      | 8 - 50                | 10                       | 500                        | 33 x 40                | 0.063                      | Vertical       | NOL                      |
| Reaction (1)  | 8 - 83                | 15                       | 30                         | 18 x 18                | 0.063                      | Vertical       | NOL                      |
| Positive (2)  | 4 - 100               | 50                       | 7                          | 4" diam                | 0.100                      | Vertical       | Consolidated Engineering |
| Reaction (3)  | 8 - 50                | 10                       | 500                        | 33 x 40                | 0.063                      | Vertical       | NOL                      |

(1) Located in temperature chamber and capable of vibrating test specimens at temperature ranging from -85° to 250° F.

(2) Used for calibration purposes only.

(3) Located in explosion-proof chamber.

## ACCELERATING MACHINES

| Title of Machine                  | Developed by - Date      | Source of Power         | Type of Release       | Bore of Barrel (inches) | Length of Barrel (feet) | Maximum Working Pressure (psi) | Maximum Force Available (pounds) | Maximum Energy Available (ft lb) | Maximum Acceleration Obtainable                          | Duration of Acceleration (milli-seconds) | Maximum Velocity Attainable (ft/sec) |
|-----------------------------------|--------------------------|-------------------------|-----------------------|-------------------------|-------------------------|--------------------------------|----------------------------------|----------------------------------|----------------------------------------------------------|------------------------------------------|--------------------------------------|
| Air Gun, Shock Testing Type 1B    | NOL<br>Feb. 1947         | Com-pressed Air         | Mechan-ical Ball Type | 5.6                     | 43                      | 3000                           | 73,900                           | 90,000                           | Empty Piston<br><u>7,400 g</u><br>2-lb load<br>6,150 g   | 10 - 40                                  | 300                                  |
| Air Gun, Shock Testing Type 2A    | NOL<br>July 1943         | Com-pressed Air         | Mechan-ical Ball Type | 15.0                    | 58                      | 1000                           | 177,000                          | 250,000                          | Empty Piston<br><u>2,600 g</u><br>5-lb load<br>2,400 g   | 10 - 40                                  | 450                                  |
| Air Gun, Shock Testing XS-1A      | NOL, under con-struction | Com-pressed Air         | Mechan-ical Ball Type | 21.0                    | 93                      | 1000                           | 346,000                          | 1,300,000                        | Empty Piston<br><u>2,880 g</u><br>25-lb load<br>2,380 g  | 20 - 60                                  | 760                                  |
| Air Gun, High g XS-2A             | NOL under con-struction  | Com-pressed Air         | Burst-ing Dia-phragm  | 5.0                     | 56-100                  | 15,000                         | 295,000                          | 300,000                          | Empty Piston<br><u>49,000 g</u><br>6-lb load<br>24,500 g | 10 - 70                                  | 1100                                 |
| Shock Tester, Square Wave Type 2A | NOL<br>June 1946         | Steel Springs or Rubber | Pull-pin Type         | --                      | --                      | --                             | 2,000*                           | 740                              | Empty Carriage, <u>57 g</u><br>2-lb load,<br>54 g        | 3 - 100                                  | 36.7                                 |

\*Force obtained by stretching the springs or rubber shock cords.

These machines operate on the principle that if a force is applied to a carriage restrained from motion, the carriage (containing the device under test) will be subjected to an acceleration proportional to the carriage mass and the applied force when the carriage is freed to move. This is usually accomplished by the operation of a mechanical release system. In the case of the 5" air gun, however, calibrated diaphragms which rupture under pressure are

# DROP TESTERS

| Title of Machine                 | Developed by - Date     | Carriage Weight (pounds) | Anvil Weight (pounds)                        | Maximum Height of Drop | Range of Velocity Change (ft/sec) | Range of Acceleration | Duration of Acceleration (milli-seconds) | Approximate Maximum Test Loads |
|----------------------------------|-------------------------|--------------------------|----------------------------------------------|------------------------|-----------------------------------|-----------------------|------------------------------------------|--------------------------------|
| Drop Tester Type 2A              | NOL<br>June 1945        | 200                      | 2050                                         | 10 ft                  | 0 - 25                            | 50 - 1500 g           | 0.6 - 2.5                                | 22" diam<br>300 lbs            |
| Drop Tester Type 3A              | NOL<br>Oct. 1945        | 100                      | 1000                                         | 12 in                  | 0 - 12                            | 50 - 1500 g           | 0.4 - 2.5                                | 10" diam<br>50 lbs             |
| Drop Tester* XD-1A               | NOL, under construction | 35                       | 2000                                         | 40 ft                  | 0 - 75                            | 50 - 50,000 g         | 0.1 - 1.0                                | 8" diam<br>10 lbs              |
| Shock Tester Sine Wave, Type 1-A | NOL<br>Jan. 1946        | 23                       | Carriage strikes impact nuts on tension rods | 2 ft                   | 0 - 16                            | 15 - 200 g            | 2.5 - 6.0                                | 7.5" diam<br>25 lbs            |
| Drop Tester**                    | NOL<br>March 1947       | 6.25                     | 140                                          | Equivalent to 1200 ft  | 0 - 275                           | 500 - 10,000 g        | 1.45 - 10                                | 8" diam<br>6 lbs               |

\*Safety devices provided for the protection of operator when testing "live" fuzes.

\*\*15"-diameter air gun used as the source of energy

In these machines, the device under test, secured to a test carriage, is brought up to a predetermined velocity (usually under the action of gravity) and is suddenly stopped. In the case of the 1200' drop tester, the action of the test piston of the 15" air gun is used to attain the required velocities. On all the machines, except the sine-wave tester, cushions of lead can be used to control the time over which the stopping action takes place, thus regulating the acceleration. On the sine-wave tester, the dimensions of the tension rods can be varied to produce this result.

## CENTRIFUGES

| Title of Machine      | Developed by - Date | Source of Power                      | Maximum Attainable Speed | Range of Acceleration Attainable | Duration of Acceleration |
|-----------------------|---------------------|--------------------------------------|--------------------------|----------------------------------|--------------------------|
| Medium speed, Type 1A | NOL<br>July 1944    | 3-hp variable-speed electric motor   | 2500 rpm                 | 10 - 1500 g                      | Indefinite*              |
| Low speed, Type 2A    | NOL<br>Aug. 1946    | 3/4-hp variable-speed electric motor | 390 rpm                  | 0.35 - 70 g                      | Indefinite*              |

\*Duration of the acceleration and the rate of change of the acceleration can be controlled by the operator.

In the centrifuges, the device being tested is secured to the arm rotating in the horizontal plane, the device being subjected to a centrifugal acceleration proportional to the speed of a rotation and the distance of the device from the center of rotation. The arm is driven by the variable-speed motor, and, since the motor speed must be varied slowly, the angular acceleration is negligible.

Detailed information on these machines is available in NOL Report No. 1056.

THE FOURTH SYMPOSIUM  
David Taylor Model Basin  
16 April 1947

LIST OF REPRESENTATIVES IN ATTENDANCE

*Office of the Chief of Naval Operations*

Capt. G. W. Stott  
Capt. A. B. Leggett  
Comdr. J. A. Coppola

*Bureau of Ships*

Capt. J. H. Mills  
Capt. Logan McKee  
Capt. A. G. Mumma  
Comdr. J. C. Radford  
Lt. Bolker  
Mr. H. E. Bethon  
Mr. L. W. Buechler  
Mr. Boxer  
Mr. L. H. Fryer  
Mr. E. S. Henning  
Mr. M. L. Henoch  
Mr. E. J. Hough  
Mr. J. V. Levy  
Mr. J. B. Lunsford  
Mr. J. D. Mayer  
Mr. W. C. Meilander  
Mr. R. Michel  
Mr. E. F. Noonan  
Mr. R. H. Oliver  
Mr. E. Rassman  
Mr. M. St. Dennis  
Mr. H. F. Smith  
Mr. T. L. Soo Hoo  
Mr. V. N. Stankoff  
Mr. R. W. Stewart

*Bureau of Ordnance*

Mr. B. C. Belyea  
Mr. J. Castelman  
Mr. C. W. Davies  
Mr. L. R. Evans  
Mr. P. H. Girouard  
Mr. D. Gold  
Mr. M. Goldberg  
Mr. J. A. S. Roy

Mr. A. H. Sellman  
Mr. D. Wertman  
Mr. A. Sussman  
Mr. D. Workman

*Bureau of Aeronautics*

Mr. B. A. Wiener

*Bureau of Yards and Docks*

Dr. Henri Marcus

*Office of Naval Research*

Mr. J. M. Crowley  
Mr. H. Boehly  
Mr. R. Robertson

*Naval Medical Research Institute*

Lt. Cdr. D. E. Goldman

*David W. Taylor Model Basin*

Capt. Saunders  
Capt. Pyne  
Capt. R. A. Hinners  
Comdr. J. O. Baker  
Comdr. A. O. Doritz  
Mr. R. T. McGoldrick  
Mr. W. J. Sette  
Mr. N. H. Jasper  
Mr. F. F. Vane  
Mr. H. L. Rich  
Mr. D. Smith  
Mr. E. O. Berdahl  
Mr. Shapiro

*Naval Gun Factory*

Capt. J. McN. Taylor  
Comdr. W. H. Cheney  
Comdr. H. A. Bowen, Jr.

*Naval Gun Factory (Cont.)*

Comdr. K. G. Robinson  
Mr. W. C. Thom  
Mr. H. N. Schofield  
Mr. S. Carpenter  
Mr. A. Holzer  
Mr. J. A. Kingsbury  
Mr. J. J. Pierano  
Mr. J. P. Strong  
Mr. A. Leventhal  
Mr. E. J. Ballou  
Mr. C. M. Ryerson  
Mr. F. A. Ross  
Mr. B. Schlachman

*Naval Ordnance Laboratory*

Mr. D. E. Marlowe  
Dr. L. W. Ball  
Mr. C. C. Vogt  
Dr. G. K. Hartman  
Mr. J. H. Armstrong  
Mr. W. G. McAdams

*National Bureau of Standards*

Mr. C. D. Romberg  
Mr. A. McPherson

*Engineering Experiment Station*

Lt. Cdr. J. M. Vallillo  
Mr. George Wohlberg  
Mr. Paul J. Shovestul

*Material Laboratory, N. Y. Naval Shipyard*

Mr. W. H. Hoppmann

*Naval Air Material Center, NAES*

Mr. David E. Weiss

*Naval Research Laboratory*

Dr. Elias Klein  
Dr. I. Vigness  
Dr. H. M. Trent  
Mr. C. B. Cunningham  
Mr. F. J. Hartz  
Mr. R. W. Conrad  
Mr. E. E. Bissell  
Mr. C. J. Bastien  
Mr. F. W. Bird  
Mr. F. B. Bury  
Dr. E. W. Kammer  
Mr. P. F. Delisi  
Mr. F. W. Struthers  
Mr. J. A. Lee  
Mr. S. D. Hart  
Mr. T. P. McCullough  
Mr. S. P. Thompson  
Mr. H. L. Wuerffell  
Mr. L. C. Cardinal  
Mr. L. M. Treitel  
Mr. A. N. Ciaffardini  
Mr. W. B. Westfield  
Mr. G. B. Wareham  
Mr. R. W. Gordon  
Mr. J. M. Taylor

## SUMMARY

The fourth Shock and Vibration Symposium was held at the David Taylor Model Basin on Wednesday, 16 April 1947, commencing at 1100.

In his greeting of the visitors, the Director, Capt. H.E. Saunders, reviewed the history of the Model Basin and of the expansion of its activities in recent years into the field of structural mechanics, and into research in shock and vibration in particular.

The Director's talk was followed by a brief motion picture showing how models are built and towed in the basin. Then came a slide demonstration of instruments and facilities for research in the field of shock and vibration, including the measurement of pressures due to underwater explosion and air blast.

At 1145, the visitors were divided into 5 groups and went on a tour covering 6 points of interest. In the model basin proper they heard a talk on the operation of the main towing carriage. In the vibration research pit were demonstrated various instrument-calibrating machines, as well as some recent types of torsionographs and the TMB electrodynamic vibration generator. In the vibration instrument laboratory, about 30 different instruments for measuring shock and vibration were on display. This exhibit covered the majority of the instruments tabulated elsewhere in this issue of the Bulletin. Also exhibited here were the TMB Carrier-Type Strain Indicator for use with metaelectric strain gages for the measurement of both static and dynamic stresses. At the vibration test stand, the TMB 5000-pound vibration generator was operated, and various types of ship-board vibration instruments were demonstrated under simulated service conditions.

At the explosion test pond, the visitors were shown the facilities for recording underwater pressure as well as those for recording shock and strain due to underwater explosions. At the blast range were shown oscillographic channels for recording blast pressures from guns up to 5 inches in caliber.

During the afternoon session, four motion pictures were shown. The first picture demonstrated the operation of the 25-ton Losenhausen vibration generator on the Liberty Ship SS PHILIP SCHUYLER during a structural investigation in which the TMB cooperated with the U.S. Maritime Commission and the Coast Guard. The second movie, loaned by Waugh Laboratories, Inc., showed the operation of vibration machines at the Losenhausen plant in Dusseldorf, Germany, before the war. One scene demonstrated the development of a fatigue failure on a large welded truss as a result of steady-state vibration. The third movie was a slow-motion demonstration of some interesting properties of the gas globe resulting from underwater explosions as revealed in studies made at TMB. The fourth picture was a BuShips picture illustrating high-impact-shock effects on ship structures and equipment.

Following the motion pictures, Mr. A.G. Brooker of the British Admiralty Mining Establishment, a guest of the Bureau of Ordnance, gave a brief talk on the particular interests of his group in shock and vibration. He also pointed out the desirability of setting up similar symposia in England.

The symposium ended with a discussion of proposed subjects for the next symposium tentatively scheduled for June. The proposals were submitted to the Agenda Committee for a final decision.

# DAVID TAYLOR MODEL BASIN SHOCK AND VIBRATION EQUIPMENT

## INTRODUCTION

The tables presented here are taken from TMB Report 563 entitled "Instruments for Measuring Vibration and Shock on Ship Structures and Machinery" which is currently in process of publication at the David Taylor Model Basin.

TABLE 1  
Accelerometers for Measurement of Steady-State Vibration

| Name                                         | Practical Frequency Range<br>CPS                                                                               | Practical Single Amplitude Range<br>g | Sensitivity                                 | Direction of Vibration                         | Method of Detection                   | Method of Recording   | Method of Damping                                 |
|----------------------------------------------|----------------------------------------------------------------------------------------------------------------|---------------------------------------|---------------------------------------------|------------------------------------------------|---------------------------------------|-----------------------|---------------------------------------------------|
| BuOrd torpedo accelerometer                  | 0 to 30                                                                                                        | 0.25 to 25                            | 0.04 in. per g on record                    | Any one                                        | Spring-mounted mass, mechanical lever | Stylus on waxed paper | Oil, not adjustable                               |
| Brush VP-5 acceleration pickup               | 10 to 500                                                                                                      | 0.001 to 10                           | About 80 mv RMS per g                       | Any one                                        | Piezoelectric crystal                 | Oscillographic        | None                                              |
| Single damped-cantilever accelerometer       | 0 to 50                                                                                                        | 0.1 to 18                             | 22.5 $\mu$ v per g per 45 volts             | Any one                                        | Metaelectric strain gage              | Oscillographic        | Oil film between parallel plates, adjustable      |
| Double cantilever accelerometer Types A to E | 10 to 800                                                                                                      | 1 to 2000, estimated                  | Varies, about 45 $\mu$ v per g per 45 volts | Any one                                        | Metaelectric strain gage              | Oscillographic        | Very little, internal damping of plastic material |
| DVL-type accelerometer                       | 0 to 35                                                                                                        | 0.02 to 5                             | 0.15 in. per g on record                    | Any one                                        | Optical lever, Tuckerman strain gage  | Photographic          | Oil, not adjustable                               |
| Jacklin 3-component linear accelerometer     | 0 to 60                                                                                                        | 0.01 to 1.5                           | 1.25 in. per g on record                    | Two horizontal and one vertical simultaneously | Optical lever                         | Photographic          | Oil film between stationary and moving surfaces   |
| Low-frequency A elements                     |                                                                                                                |                                       | 0.80 in. per g on record                    |                                                |                                       |                       |                                                   |
| Low-frequency B elements                     |                                                                                                                | 0.02 to 2.3                           | About 0.15 in. per g                        |                                                |                                       |                       |                                                   |
| High-frequency A elements                    | 0 to 150                                                                                                       | 0.06 to 12.5                          | About 0.15 in. per g                        |                                                |                                       |                       |                                                   |
| High-frequency B elements                    |                                                                                                                |                                       |                                             |                                                |                                       |                       |                                                   |
| Jacklin 3-component angular accelerometer    | 0 to 25                                                                                                        | 0.1 to 15 rad/sec <sup>2</sup>        | About 0.1 in. per rad/sec <sup>2</sup>      | Angular about 3 perpendicular axes             | Optical lever                         | Photographic          | Oil film between stationary and moving surfaces   |
| Jacklin 6-component accelerometer            | Combines in one recorder 3 linear elements and 3 angular elements with the same characteristics as those above |                                       |                                             |                                                |                                       |                       |                                                   |

The tables are being published at this time for the reference and convenience of those who attended the Shock and Vibration Symposium held at the David Taylor Model basin on 16 April 1947.

The figure numbers given in the tables refer to figures in TMB Report 563, and should be disregarded in the tabulations presented here.

TABLE 1 (continued)

| Natural Frequency of Element CPS    | Weight pounds                              | Overall Dimensions (LxWxH) or (DxH) inches                    | Power Required       | Accessory Equipment Required                | Method of Mounting on Vibrating Structure | Figure Number | Remarks                                                                                                                             |
|-------------------------------------|--------------------------------------------|---------------------------------------------------------------|----------------------|---------------------------------------------|-------------------------------------------|---------------|-------------------------------------------------------------------------------------------------------------------------------------|
| 35                                  | 7 3/4                                      | 5 x 10                                                        | 6-v dry cell         | Timer, if desired                           | Bolted or clamped to structure            | 7             | Holds maximum of 40 inches of paper which permits 30 seconds of record                                                              |
| 1500                                | 0.4                                        | 3 x 2                                                         | 110-v a.c.           | Usual electronic equipment*                 | Held against or clamped to structure      | 8             |                                                                                                                                     |
| 215                                 | 4.2                                        | 4 1/2 x 2 x 6                                                 | 110-v a.c.           | Usual electronic equipment*                 | Bolted or clamped to structure            | 9             | Development inactive.                                                                                                               |
| 200<br>1400<br>1800<br>2400<br>3500 | Type D<br>1.0                              | Type D<br>8 x 2 1/2 x 2                                       | 110-v a.c.           | Battery box and usual electronic equipment* | Bolted or clamped to structure            | 10            | Not currently in use, requires filter. Of historic interest only. Statham accelerometer employs similar principle more effectively. |
| 67                                  | 98 (with recorder)                         | 17 x 12 x 14                                                  | 110-v a.c.           | Tuckerman recorder and timer                | Bolted or clamped to structure            | 11            | Not currently in use.                                                                                                               |
| About 100                           | Recorder,<br>30;<br>control<br>unit,<br>30 | Recorder,<br>7 x 11 x 14;<br>control unit,<br>12 x 5 3/8 x 10 | 35-amp,<br>12-v d.c. | None                                        | Bolted or clamped to structure            | 12            | Each recorder is capable of holding 6 elements. All elements are interchangeable.                                                   |
| About 250                           |                                            |                                                               |                      |                                             |                                           |               |                                                                                                                                     |
| About 50                            | Recorder,<br>30;<br>control<br>unit,<br>30 | Recorder,<br>7 x 11 x 14;<br>control unit,<br>12 x 5 3/8 x 10 | 35-amp,<br>12-v d.c. | None                                        | Bolted or clamped to structure            | 12            | On order.                                                                                                                           |
|                                     |                                            |                                                               |                      |                                             |                                           | 12            | On order.                                                                                                                           |

TABLE 1 (continued)

| Name                                                                                                                                                                                        | Practical Frequency Range<br>CPS                             | Practical Single Amplitude Range<br>g                                                            | Sensitivity                                  | Direction of Vibration                         | Method of Detection                                      | Method of Recording   | Method of Damping       |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|--------------------------------------------------------------------------------------------------|----------------------------------------------|------------------------------------------------|----------------------------------------------------------|-----------------------|-------------------------|
| Pallograph-type accelerometer                                                                                                                                                               |                                                              |                                                                                                  | On record, inches per g                      |                                                |                                                          |                       |                         |
| Group I**                                                                                                                                                                                   | 0 to 1<br>0 to 1<br>0 to 1.5<br>0 to 2<br>0 to 2.5<br>0 to 3 | 0.001 to 0.08<br>0.002 to 0.16<br>0.004 to 0.34<br>0.007 to 0.63<br>0.013 to 1.0<br>0.016 to 1.0 | 5.76<br>2.63<br>1.33<br>0.71<br>0.35<br>0.28 | Vertical only                                  | Spring-mounted weight, mechanical lever                  | Stylus on waxed paper | Air dashpot, adjustable |
| Group II**                                                                                                                                                                                  | 0 to 2<br>0 to 3<br>0 to 4<br>0 to 5<br>0 to 6               | 0.03 to 1.2<br>0.05 to 2.0<br>0.10 to 4.3<br>0.15 to 6.8<br>0.20 to 9.0                          | 0.33<br>0.20<br>0.10<br>0.066<br>0.05        | Any one normal to base                         |                                                          |                       |                         |
| Consolidated accelerometer                                                                                                                                                                  | 0 to 35                                                      | 0.02 to 15                                                                                       | 25 mv per g with 15-v carrier                | Any one                                        | Seismic inductance, variable reluctance                  | Oscillographic        | Magnetic                |
| Shrader 3-component accelerometer                                                                                                                                                           | 0 to 50                                                      | 0.05 to 5                                                                                        | About 0.3 in. per g                          | Two horizontal and one vertical simultaneously | Optical lever                                            | Photographic          | Air dashpot             |
| Wimperis accelerometer                                                                                                                                                                      | 0 to 0.25                                                    | 0.1 to 8.0 ft/sec <sup>2</sup>                                                                   | 1/4 in. per ft/sec <sup>2</sup> on scale     | Horizontal                                     | Mechanical lever                                         | Pointer on scale      | Permanent magnet        |
| Statham accelerometer R-500-700                                                                                                                                                             | 0 to 850                                                     | 1 to 500                                                                                         | About 1/5 mv per g (max)                     | Any one normal to base                         | Strain wires forming bridge circuit support inertia mass | Oscillographic        | Organo-silicon fluid    |
| Statham accelerometer Ar-12V-250                                                                                                                                                            | 0 to 150                                                     | 0.1 to 12                                                                                        | About 3 mv per g (max)                       | Any one normal to base                         | Strain wires forming bridge circuit support inertia mass | Oscillographic        | Organo-silicon fluid    |
| Statham accelerometer S-1.5-120                                                                                                                                                             | 0 to 60                                                      | 0.01 to 1.5                                                                                      | About 10 mv per g (max)                      | Any one parallel to base                       | Strain wires forming bridge circuit support inertia mass | Oscillographic        | Organo-silicon fluid    |
| ** The springs listed in Group I replace the pallograph displacement spring. The springs listed in Group II are used with a special weight and two-spring suspension as shown in Figure 13. |                                                              |                                                                                                  |                                              |                                                |                                                          |                       |                         |

TABLE 1 (continued)

| Natural Frequency of Element CPS                                                                                                                                                                | Weight pounds | Overall Dimensions (LxWxH) or (DxH) inches | Power Required    | Accessory Equipment Required                                     | Method of Mounting on Vibrating structure | Figure Number | Remarks                                        |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|--------------------------------------------|-------------------|------------------------------------------------------------------|-------------------------------------------|---------------|------------------------------------------------|
| 2.16<br>2.76<br>3.83<br>5.35<br>6.79<br>7.48                                                                                                                                                    | 40            | 20 x 8 x 14                                | 110-v a.c.        | Synchronous timer                                                | Bolted or clamped to structure            | 13            | Adapted from Type B pallograph.                |
| 5.42<br>7.00<br>9.9<br>12.1<br>14.0                                                                                                                                                             |               |                                            |                   |                                                                  |                                           |               | Uses special weight and two-spring suspension. |
|                                                                                                                                                                                                 | 0.8           | 2 3/4 x 2 1/2 x 2 3/4                      | 110-v a.c.        | 1000-CPS bridge, usual electronic equipment*                     | Bolted or clamped to structure            | 14            |                                                |
| About 100                                                                                                                                                                                       | 15            | 6 x 5 1/2 x 9 1/2                          | 6-v d.c.          | None                                                             | Bolted or clamped to structure            | 15            |                                                |
| About 1.0                                                                                                                                                                                       | 2             | 4 x 2 1/2                                  | None              | None                                                             | Placed on horizontal plane                | 16            | May be photographed for recording.             |
| 1670                                                                                                                                                                                            | 0.5           | 2 x 1 1/4 x 2 1/2                          | 20-v d.c. (max)   | 5-KC carrier, power supply, oscillograph                         | Bolted to structure (5-40 screws)         | 17            |                                                |
| 300                                                                                                                                                                                             | 0.5           | 2 x 1 1/4 x 2 1/2                          | 12.5-v d.c. (max) | Modified TMB 1-A strain amplifier                                | Bolted to structure (5-40 screws)         | 17            |                                                |
| 115                                                                                                                                                                                             | 0.8           | 2 3/8 x 1 3/4 x 2 3/8                      | 5-v d.c. (max)    | Usual electronic equipment* or modified TMB 1-A strain amplifier | Bolted to structure (5-40 screws)         | 17            |                                                |
| * Usual electronic equipment consists of amplifier and power supply; Variac transformer and regulator; oscillator and microvolter; cathode-ray oscillograph and camera, or string oscillograph. |               |                                            |                   |                                                                  |                                           |               |                                                |

TABLE 2

## Instruments for Indicating the Amplitude of Steady-State Vibration

| Name                                        | Practical Frequency Range* CPM | Practical Single Amplitude Range* mils | Direction of Vibration  | Method of Detection                                     | Method of Indication       | Natural Frequency of Element CPM | Weight pounds          |
|---------------------------------------------|--------------------------------|----------------------------------------|-------------------------|---------------------------------------------------------|----------------------------|----------------------------------|------------------------|
| Cordero vibrometer                          | 500 to 2000                    | 0.5 to 15                              | Any one                 | Mechanical lever                                        | Vibrating arm on scale     | 300                              | 2                      |
| Modified Cordero vibrometer                 | 500 to 2000                    | 1 to 35                                | Any one                 | Mechanical lever                                        | Vibrating arm on scale     | About 300                        | 2 1/2                  |
| GR vibration meter and Shure crystal pickup | 120 to 30,000                  | 0.05 to 30,000                         | Any one                 | Piezoelectric crystal pickup and integrating circuits   | Meter reading of amplitude | 90,000                           | Pickup, 0.8; meter, 23 |
| Karelitz vibrometer                         | 400 to 2000                    | 0.5 to 25                              | Vertical and horizontal | Direct measurement of motion relative to seismic weight | Dial gage                  | 200                              | 35                     |
| Westinghouse hand vibrometer                | 600 to 6000                    | 1 to 50                                | Any one                 | Direct measurement of motion relative to seismic weight | Dial gage                  | About 400                        | 4                      |

\* The ranges of frequencies and amplitudes given are not necessarily concurrent, i.e., the minimum amplitude cannot always be measured at the lowest frequency since enough force must be produced to overcome the inherent

TABLE 3

## Instruments for Indicating the Frequency of Steady-State Vibration

| Name                                                | Practical Frequency Range CPM                                                   | Method of Detection                                         | Method of Indication                                              | Weight pounds         | Overall Dimensions (LxWxD) or (DxDH) inches           |
|-----------------------------------------------------|---------------------------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------------|-----------------------|-------------------------------------------------------|
| Frahm's reeds                                       | Single-row unit<br>1400 to 2000                                                 | Resonant vibration of a reed at its natural frequency       | Reed with largest amplitude indicates correct frequency           | 1 1/2                 | 5 3/4 x 1 3/4 x 4                                     |
|                                                     | Double-row units<br>800 to 1400<br>1500 to 3000<br>2500 to 5000<br>4500 to 9000 |                                                             |                                                                   | 2                     | 5 3/4 x 2 3/4 x 4                                     |
| Westinghouse reed vibrometer                        | 500 to 20,000                                                                   | Adjustment of length of reed to give proper frequency       | Resonant vibration of reed at proper frequency indicated on scale | 0.5                   | 9 1/4 x 1 3/4 x 1 1/4                                 |
| Strobomeca (Rotoscope)                              | 500 to 8000                                                                     | Rotational speed of slotted disk is varied to "stop" motion | Frequency corresponding to correct speed indicated on scale       | 0.6                   | 2 3/4 x 2 5/8                                         |
| Strobotac                                           | 600 to 14,500                                                                   | Variable frequency flashing light; stroboscopic principle   | Flashing Frequency indicated on scale                             | 9                     | 7 1/2 x 8 1/2 x 9 1/2                                 |
| Strobolux                                           | 600 to 6000                                                                     | Variable frequency flashing light; stroboscopic principle   | Flashing frequency indicated on scale                             | 32                    | 12 x 11 x 12                                          |
| Communications Measurement Laboratories Stroboscope | 600 to 600,000                                                                  | Variable frequency flashing light; stroboscopic principle   | Flashing frequency indicated on scale                             | Probe, 1; cabinet, 50 | Probe, 5 3/4 x 2 x 2; cabinet, 16 1/8 x 9 3/4 x 8 3/4 |

TABLE 2 (continued)

| Overall Dimensions<br>(LxWxH) or (DxH)<br>inches       | Power<br>Required               | Method of Mounting<br>on Vibrating<br>Structure | Figure<br>Number | Remarks                                                                                                                                                                                                                   |
|--------------------------------------------------------|---------------------------------|-------------------------------------------------|------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 6 x 2 1/2 x 1                                          | None                            | Held against<br>structure                       | 18a              | Good for qualitative check<br>of amplitude.                                                                                                                                                                               |
| 6 x 2 1/2 x 1 1/2                                      | None                            | Held against<br>structure                       | 18b              | Good for qualitative check<br>of amplitude.                                                                                                                                                                               |
| Pickup,<br>2 1/2 x 2 1/2 x 2;<br>meter,<br>13 x 9 x 13 | Self-<br>contained<br>batteries | Held or clamped<br>against structure            | 19               | Pickup is accelerometer. Meter reads<br>acceleration or integrates to give<br>velocities and displacements. May be<br>used with GR vibration analyzer which<br>weighs 32 pounds and is 16 1/2 x 9 1/2<br>x 10 1/4 inches. |
| 11 1/2 x 4 1/2 x 10                                    | None                            | Set or clamped<br>on structure                  | 20               |                                                                                                                                                                                                                           |
| 4 x 3                                                  | None                            | Held against<br>or set on<br>structure          | 21               | Hand-held operation preferable.                                                                                                                                                                                           |

friction of the particular instrument; conversely, the maximum amplitude listed cannot always be measured at the maximum frequency.

TABLE 3 (continued)

| Power<br>Required | Method of Mounting on<br>Vibrating Structure                       | Figure<br>Number | Remarks                                                                                                            |
|-------------------|--------------------------------------------------------------------|------------------|--------------------------------------------------------------------------------------------------------------------|
| None              | Set on or near structure                                           | 22               | Other units up to 12,500<br>CPM on order.                                                                          |
| None              | Held against structure                                             | 23               | 0.35-inch to 0.5-inch<br>(depending on instrument)<br>motion of reed equals<br>approximately one mil<br>amplitude. |
| None              | Held in hand; structure<br>viewed through rotating<br>slotted disk | 24               | Strong light is required for<br>effective use. Use upper 85<br>per cent of scale, lower 15<br>per cent unreliable  |
| 110-v a.c.        | Held in hand or set on<br>convenient base                          | 25               | Dim surroundings required<br>for effective use.                                                                    |
| 110-v a.c.        | Held in hand or set on<br>convenient base                          | 26               | Gives much stronger light than<br>Strobotac; Strobotac used for<br>frequency control.                              |
| 110-v a.c.        | Held in hand or set on<br>convenient base                          | 27               | Dim surrounds required for<br>effective use. Use d-c<br>illuminator only when necessary.                           |

TABLE 4  
Instruments for Recording Linear Vibrations

| Name                                            | Practical Frequency Range* CPM              | Practical Single Amplitude Range* mils        | Sensitivity or Magnification                            | Direction of Vibration                              | Method of Detection                                      | Method of Recording                   | Method of Damping                 |
|-------------------------------------------------|---------------------------------------------|-----------------------------------------------|---------------------------------------------------------|-----------------------------------------------------|----------------------------------------------------------|---------------------------------------|-----------------------------------|
| Brush DP-1 vibration pickup                     | 600 to 6000                                 | 0.01 to about 25                              | 0.28 v RMS per mil                                      | Any one                                             | Piezoelectric crystal, seismically mounted               | Oscillographic                        | None                              |
| Cox vibration recorder                          | 400 to 3000                                 | 2 to 350                                      | Adjustable 1, 2, 4, or 8                                | Vertical or horizontal (separate adaptors required) | Seismic weight, mechanical transmission of motion        | Stylus on waxed paper, 6 paper speeds | Friction of stylus on wax         |
| TWB electrical vibration pickup (pendulum-type) | 200 to 2000                                 | 0.1 to 250                                    | Up to 1000                                              | Horizontal                                          | Seismic pendulum, variable transformer coupling          | Oscillographic                        | Inherent friction                 |
| Type A pallograph                               | 60 to 700 vertical, 120 to 700 horizontal   | 5 to 500                                      | 1.75                                                    | Vertical but may be adapted for horizontal          | Seismic pendulum, mechanical lever                       | Stylus on waxed paper                 | Inherent friction                 |
| Type B pallograph                               | 50 to 1000 vertical, 170 to 1000 horizontal | 3 to 225                                      | 2.0                                                     | Vertical but may be adapted for horizontal          | Seismic pendulum, mechanical lever                       | Stylus on waxed paper                 | Air dashpot, adjustable           |
| Type C pallograph                               | 150 to 1000                                 | 2 to 150                                      | 3.0                                                     | Horizontal                                          | Seismic pendulum, mechanical lever                       | Stylus on waxed paper                 | Air dashpot, adjustable           |
| Type H pallograph                               | 80 to 1800                                  | 1 to 250                                      | Adjustable 2, 4, or 6                                   | Horizontal                                          | Seismic pendulum, mechanical lever                       | Stylus on waxed paper                 | Air dashpot, adjustable           |
| Type V pallograph                               | 40 to 1800                                  | 1 to 250                                      | Adjustable 2, 4, or 6                                   | Vertical                                            | Seismic pendulum, mechanical lever                       | Stylus on waxed paper                 | Air dashpot, adjustable           |
| Photoelectric vibration pickup                  | 300 to 3000                                 | 0.5 to 125                                    | 4 mv RMS per mil single                                 | Vertical                                            | Seismic pendulum, photoelectric cell                     | Oscillographic                        |                                   |
| Shrader tridimensional vibrograph               | 450 to 3000                                 | About 0.5 to 25                               | About 50                                                | Vertical and two horizontal simultaneously          | Seismic weight, optical lever                            | Photographic                          | Felt in coil springs              |
| Consolidated large linear-vibration pickup      | 300 to 18,000                               | 1 to 750                                      | 75 mv per in./sec                                       | Vertical or horizontal (separate units)             | Seismic magnet moving along a coil                       | Oscillographic                        | Oil, adjustable                   |
| Consolidated small linear-vibration pickup      | 900 to 60,000                               | 0.1 to 250 (varies with frequency)            | 78 mv per in./sec                                       | Vertical or horizontal (separate units)             | Seismic magnet moving along a coil                       | Oscillographic                        | Oil                               |
| Consolidated Type 4-102 velocity pickup         | 500 to 42,000                               | 0.05 to 700 vertical, 0.05 to 1000 horizontal | 110 mv per in./sec                                      | Any one                                             | Seismic magnet moving along a coil                       | Oscillographic                        | Oil                               |
| Type LE Westinghouse vibrograph                 | 600 to 15,000                               | 0.1 to 25                                     | 8 1/2 mechanical, 40 microscope                         | Any one                                             | Seismic weight, mechanical lever                         | Stylus on celluloid film              | Friction of stylus on celluloid   |
| Askania vibrograph                              | 30 to 6000                                  | 1 to 200                                      | 6 times, with attachment to reduce to 2 times or 1 time | Any one                                             | Spring-loaded pickup, probe attached to mechanical lever | Stylus on waxed paper                 | Friction of stylus on waxed paper |

\* The ranges of frequencies and amplitudes given are not necessarily concurrent, i.e., the minimum amplitude cannot always be measured at the lowest frequency since enough force must be produced to overcome the inherent friction of the particular instrument; conversely, the maximum amplitude listed cannot always be measured at the maximum frequency.

TABLE 4 (continued)

| Natural Frequency of Element CPM  | Weight pounds | Overall Dimensions (LxWxH) or (DxD) inches | Power Required                        | Accessory Equipment Required | Method of Mounting on Vibrating Structure | Figure Number | Remarks                                                                                                                                                                                                                                                       |
|-----------------------------------|---------------|--------------------------------------------|---------------------------------------|------------------------------|-------------------------------------------|---------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| About 720 when suspended by probe | 0.6           | 3 1/2 x 2 3/4                              | 110-v a.c.                            | Usual electronic equipment** | Hand-held with probe against structure    | 28            |                                                                                                                                                                                                                                                               |
| 270 horizontal, 285 vertical      | 29            | 12 x 9 1/4 x 9 1/2                         | 110-v a.c. and 6-v d.c.               | None                         | Set on, bolted, or clamped to structure   | 29            | Adapter added to Cox torsigraph to convert for linear vibrations.                                                                                                                                                                                             |
| 60                                | 30            | 7 1/2 x 10 x 16                            | 110-v a.c.                            | Usual electronic equipment** | Set on, bolted, or clamped to structure   | 30            |                                                                                                                                                                                                                                                               |
| 20 vertical, 40 horizontal        | 110           | 32 x 9 1/2 x 23 3/4                        | 110-v a.c.                            | Synchronous timer            | Set on, bolted, or clamped to structure   | 31            | May be adapted for recording horizontal vibrations.                                                                                                                                                                                                           |
| 15 vertical, 60 horizontal        | 40            | 20 x 8 x 14                                | 110-v a.c.                            | Synchronous timer            | Set on, bolted, or clamped to structure   | 32            | May be adapted for recording horizontal vibrations.                                                                                                                                                                                                           |
| 60                                | 25            | 16 x 7 1/2 x 11                            | 110-v a.c.                            | Synchronous timer            | Set on, bolted, or clamped to structure   | 33            |                                                                                                                                                                                                                                                               |
| 40                                | 60            | 18 x 9 x 11 1/2                            | 110-v a.c.                            | Synchronous timer            | Set on, bolted, or clamped to structure   | 34            |                                                                                                                                                                                                                                                               |
| 20                                | 75            | 18 1/2 x 9 1/2 x 14 1/2                    | 110-v a.c.                            | Synchronous timer            | Set on, bolted, or clamped to structure   | 35            | May be adapted for recording horizontal motions.                                                                                                                                                                                                              |
| 215                               | 14            | 12 x 6 x 7                                 | 110-v a.c.                            | Usual electronic equipment** | Set on, bolted, or clamped to structure   | 36            | In process of development.                                                                                                                                                                                                                                    |
| 300                               | 20            | 6 x 8 x 11                                 | 6-v d.c. or 110-v a.c. with rectifier | None                         | Set on, bolted, or clamped to structure   | 37            | Instrument has been modified to give magnification listed.                                                                                                                                                                                                    |
| 240                               | 6.8           | 6 1/2 x 4 1/2 x 4                          | 110-v a.c.                            | Usual electronic equipment** | Set on, bolted, or clamped to structure   | 38            | Velocity meter, integrating circuit used.                                                                                                                                                                                                                     |
| 300                               | 0.33          | 2 x 3                                      | 110-v a.c.                            | Usual electronic equipment** | Set on, bolted, or clamped to structure   | 39            | Velocity meter, integrating circuit used.                                                                                                                                                                                                                     |
| 540 (damped)                      | 0.6           | 2 x 2 3/4                                  | None, self-generating                 | Usual electronic equipment** | Set on, bolted, or clamped to structure   | 40            | 900-ohm noninductive-wound d-c coil resistance, velocity meter, integrating circuit used. Sensitivity gradually decreases with increasing single amplitudes above 300 mils. Frequency response flat plus or minus 5 per cent over entire range up to 25 mils. |
| 400                               | 10            | 7 1/2 x 5 x 4 3/4                          | None                                  | None                         | Set on, bolted, or clamped to structure   | 41            | May be used hand-held with a probe adapter. At 25 mils single amplitude the maximum frequency is 3000 CPM using probe, i.e., at accelerations below 6.25 g.                                                                                                   |
| 300                               | 3.2           | 7 x 5 x 3                                  | Flashlight battery for timer          | None                         | Hand-held with probe against structure    | 42            | Capable of recording deflections up to 1 inch as long as the acceleration is less than 20 g.                                                                                                                                                                  |

\*\* Usual electronic equipment consists of amplifier and power supply; variac transformer and voltage regulator; oscillator and microvolter; cathode-ray oscillograph and camera, or string oscillograph.

TABLE 5  
Instruments for Recording Torsional Vibrations

| Name                                                                                                                                                                                                                                                                                                                                                            | Practical Frequency Range* CPM | Practical Single Amplitude Range* degrees | Sensitivity or Magnification                     | Method of Detection                                            | Method of Recording        | Method of Damping                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|-------------------------------------------|--------------------------------------------------|----------------------------------------------------------------|----------------------------|-----------------------------------|
| Cox torsigraph                                                                                                                                                                                                                                                                                                                                                  | 600 to 5000                    | 0.03 to 3.5                               | About 0.4 in./deg (max)                          | Inertia element, bell crank transmission                       | Stylus on waxed paper      | Friction of stylus on waxed paper |
| Phase-shift torsigraph                                                                                                                                                                                                                                                                                                                                          | 500 to 50,000**                | Depends on pickup gear, about 0.03 to 5   | Depends on pickup gear, about 1/2 in. per degree | Phase-shift in gear-tooth carrier wave due to vibration        | Oscillo-graphic            | None                              |
| Photoelectric torsional vibration pickup                                                                                                                                                                                                                                                                                                                        | 500 to 50,000**                | About 0.01 to 5                           | Varies with light intensity                      | Inertia element with slotted cylinder, photoelectric detection | Oscillo-graphic            | Dry friction                      |
| Consolidated torsional vibration pickup                                                                                                                                                                                                                                                                                                                         | 900 to 60,000**                | 0.075 to 5 (varies with frequency)        | 1.2 mv per deg/sec                               | Inertia element, magnet moving about coil                      | Oscillo-graphic            | Dry friction                      |
| General Motors mechanical torsigraph                                                                                                                                                                                                                                                                                                                            | 1000 to 20,000**               | 0.05 to 2.5                               | About 0.2 in. per degree                         | Inertia element, mechanical lever                              | Stylus on sensitized paper | Dry friction                      |
| TMB-Sperry torsional vibration pickup                                                                                                                                                                                                                                                                                                                           | 900 to 60,000**                | 0.075 to 5                                | About 1.2 mv per deg/sec                         | Inertia element, magnet moving about coil                      | Oscillo-graphic            | Dry friction                      |
| * The ranges of frequencies and amplitudes given are not necessarily concurrent, i.e., the minimum amplitude cannot always be measured at the lowest frequency since enough force must be produced to overcome the inherent friction of the particular instrument; conversely, the maximum amplitude listed cannot always be measured at the maximum frequency. |                                |                                           |                                                  |                                                                |                            |                                   |

TABLE 5 (continued)

| Natural Frequency of Element CPM                                                                                                                                                                                   | Weight pounds                                                                                            | Overall Dimensions (LxWxH) or (DxD) inches                                               | Power Required          | Accessory Equipment Required                            | Method of Attaching to Shaft                                                             | Figure Number | Remarks                                                                                                                |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|-------------------------|---------------------------------------------------------|------------------------------------------------------------------------------------------|---------------|------------------------------------------------------------------------------------------------------------------------|
| About 300                                                                                                                                                                                                          | 28 1/2                                                                                                   | 12 x 9 1/4 x 9 1/2                                                                       | 110-v a.c. and 6-v d.c. | None                                                    | Attached by belt on a pulley                                                             | 43            | Amplitude range may be increased by using small pulley or engine shaft.                                                |
|                                                                                                                                                                                                                    | Power supply 24 1/2<br>Detector unit 12 1/2<br>Pickup gears 3, 60 teeth<br>6, 120 teeth<br>11, 120 teeth | 14 3/4 x 6 x 10 1/4<br>14 1/8 x 8 x 9<br>3 5/8 x 5 1/2<br>5 3/4 x 6 1/2<br>9 3/4 x 4 3/8 | 110-v a.c.              | Cathode-ray oscillograph and camera                     | Pickups fastened to end of shaft. Pickup gear (split) may be welded anywhere along shaft | 44            | Principal component of torsigraph is the phase-shift detector gear; must be devised for each new job.                  |
| About 400                                                                                                                                                                                                          | 8                                                                                                        | 3 1/2 x 5 3/4                                                                            | 110-v a.c. and 6-v d.c. | Light-ring unit and cathode-ray oscillograph and camera | Fastened to end of shaft with set screws on an adaptor for a 1-inch collet               | 45            | Currently under development at TMB. May be calibrated by inserting plug and rotating case relative to inertia element. |
| 600                                                                                                                                                                                                                | 3 1/2                                                                                                    | 3 x 5                                                                                    | 110-v a.c.              | Sperry calibrator, amplifier, and string oscillograph   | Fastened to end of shaft with set screws                                                 | 46            | Velocity meter principle, integrating circuit used. Method of attaching to shaft to be redesigned for 1-inch collet.   |
| 480                                                                                                                                                                                                                | 9 1/2                                                                                                    | 6 1/4 x 10                                                                               | None                    | None                                                    | Fastened to end of shaft with 1-inch collet                                              | 47            | Celluloid chart provided for analyzing polar diagram obtained.                                                         |
| About 600                                                                                                                                                                                                          | 5 1/2                                                                                                    | 3 1/2 x 5 1/2                                                                            | 110-v a.c.              | Sperry calibrator, amplifier, and string oscillograph   | Fastened to end of shaft with 1-inch collet                                              | 48            |                                                                                                                        |
| ** The upper frequency limit is approximate; it is based on manufacturers' data or on consideration of the mechanical construction of the pickup. Present TMB facilities permit calibration only up to 10,000 CPM. |                                                                                                          |                                                                                          |                         |                                                         |                                                                                          |               |                                                                                                                        |

TABLE 6

## Displacement and Velocity Meters for Measurement of Transient Vibration

| Name                                       | Practical Frequency Range* CPM | Practical Single Amplitude Range* inches | Sensitivity or Magnification | Direction of Vibration                  | Method of Detection                                  | Method of Recording            | Method of Damping           |
|--------------------------------------------|--------------------------------|------------------------------------------|------------------------------|-----------------------------------------|------------------------------------------------------|--------------------------------|-----------------------------|
| British-type velocity meter                | 400 to 5000                    | 0.001 to 1.0                             | About 30 mv per in./sec      | Any one                                 | Seismic weight, electromagnet moves relative to coil | Oscillographic                 | Inherent friction, low      |
| Modified British-type velocity meter       | 400 to 5000                    | 0.001 to 1.0                             | About 30 mv per in./sec      | Any one                                 | Seismic weight, electromagnet moves relative to coil | Oscillographic                 | Inherent friction, low      |
| Consolidated large linear vibration pickup | 300 to 18,000                  | 0.001 to 0.750                           | 75 mv per in./sec            | Vertical or horizontal (separate units) | Seismic weight, electromagnet moves relative to coil | Oscillographic                 | Oil, adjustable             |
| Shock displacement gage                    | 800 to 10,000                  | 0.01 to 1.0                              | 1.0 inch per inch            | Any one                                 | Seismic weight, direct recording                     | Scriber on polished metal disk | Friction of scriber on disk |

\* The ranges of frequencies and amplitudes given are not necessarily concurrent, i.e., the minimum amplitude cannot always be measured at the lowest frequency since enough force must be produced to overcome the inherent friction of the particular instrument; conversely, the maximum amplitude listed cannot always be measured at the maximum frequency.

TABLE 6 (continued)

| Natural Frequency of Element CPM   | Weight pounds | Overall Dimensions (LxWxH) or (DxH) inches | Power Required          | Accessory Equipment Required | Method of Mounting on Vibrating Structure               | Figure Number | Remarks                                                                                                                                                   |
|------------------------------------|---------------|--------------------------------------------|-------------------------|------------------------------|---------------------------------------------------------|---------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
| About 180 vertical, 240 horizontal | 47            | 8 x 9 1/2                                  | 110-v a.c. and 6-v d.c. | Usual electronic equipment** | Base bolted to structure                                | 49            | Effective weight, 37 pounds; weight of seismic magnet, 10 pounds.                                                                                         |
| About 180 vertical, 240 horizontal | 30            | 8 x 10 1/2                                 | 110-v a.c. and 6-v d.c. | Usual electronic equipment** | Screwed to expendable base which is welded to structure | 50            | Currently being modified to decrease the weight, strengthen the case, and eliminate pitting between roller bearings and seismic magnet of original meter. |
| 240                                | 6.8           | 6 1/2 x 4 1/2 x 4                          | 110-v a.c.              | Usual electronic equipment** | Base bolted to structure                                | 38            | Used without integrating circuit for velocity recording                                                                                                   |
| 520                                | 89            | 25 x 12 x 15                               | 110-v a.c.              | None                         | Base bolted to structure                                | 51            |                                                                                                                                                           |

\*\* Usual electronic equipment consists of amplifier and power supply; Variac transformer and regulator; oscillator and microvolter; cathode-ray oscillograph and camera, or string oscillograph.

TABLE 7  
Indicating Accelerometers for Measurement of Transient Vibration

| Name                             | Practical Single Amplitude Range g | Method of Indication                                                                 | Meaning of Indication                                                                                                                                                                                                                   | Method of Damping                       | Natural Frequency of Element CPS | Weight pounds |
|----------------------------------|------------------------------------|--------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|----------------------------------|---------------|
| Copper-ball accelerometer        | 10 to 3200                         | Flattening of small copper ball by large steel ball                                  | Amount of flattening of target is presumed to be a measure of the peak acceleration                                                                                                                                                     | None                                    |                                  | 1.5           |
| Mass-plug accelerometer          | 100 to 4500                        | Fracture of bakelite plug                                                            | Fracture of plug presumed to indicate that a definite value of acceleration has been attained                                                                                                                                           | None                                    | 500 to 2600                      | 1.25          |
| Multifrequency impact gage       | 5 to 20,000                        | Total displacement of each of 10 reeds of different frequency scribed on waxed paper | Total displacement of reeds considered to indicate applied impulsive velocity. Frequency spectrum of shock indicated. Good for comparison of severity of similar shocks                                                                 | Friction of scribe on wax               | 25 to 2000                       | 19 1/2        |
| NRL contact accelerometer        | 5 to 500                           | Electrical indication of breaking or making of contact of preloaded spring-mass unit | Break-contact is presumed to indicate attainment of a definite value of acceleration. Use of a number of cells permits bracketing the peak value. Make-contact may be considered to indicate impulsive velocity as well as acceleration | None                                    |                                  | 0.1           |
| Putty gage                       | 25 to 2000                         | Indentation of conical rod in putty cylinder, 8 mass-spring units per gage           | Amount of indentation in putty is supposed to indicate peak acceleration. May be interpreted in terms of effective impulsive velocity                                                                                                   | Inherent friction plus putty resistance | 35 to 200                        | 6.2           |
| TMB 7-reed contact accelerometer | 50 to 10,000                       | Electrical indication of breaking or making of contact of preloaded cantilever reeds | Break-contact is presumed to indicate attainment of a definite value of acceleration. Use of a number of cells permits bracketing the peak value. Make-contact may be considered to indicate impulsive velocity as well as acceleration | None                                    | 90 to 3900                       | 3 1/4         |

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TABLE 7 (continued)

| Overall Dimensions<br>(LxWxH) or (DxH)<br>inches | Power<br>Required | Method of Mounting<br>on Vibrating<br>Structure             | Figure<br>Number | Remarks                                                                             |
|--------------------------------------------------|-------------------|-------------------------------------------------------------|------------------|-------------------------------------------------------------------------------------|
| 2 1/2 x 2 1/2 x<br>2 1/2                         | None              | Bolted to<br>structure                                      | 52               |                                                                                     |
| 1 1/2 x 2 3/4                                    | None              | Screwed to 1/2-inch<br>stud which is<br>welded to structure | 53               | Several plugs are used<br>in an attempt to bracket<br>the actual peak acceleration. |
| 9 5/8 x 3 5/8 x 9                                | None              | Bolted to<br>structure                                      | 54               | Units containing 12 reeds<br>currently being designed.                              |
| 7-cell holder,<br>6 x 4 x 4 1/2                  | 110-v a.c.        | Clamped in 7-cell<br>holder which is<br>bolted to structure | 55               | Utilized TMB neon make-or-<br>break indicator; see Figure 58.                       |
| 3 x 5 1/2                                        | None              | Bolted to<br>structure                                      | 56               |                                                                                     |
| 3 3/4 x 3 1/2                                    | 110-v a.c.        | Screwed to 1/2-inch<br>stud which is<br>welded to structure | 57               | Utilizes TMB neon make-or-<br>break indicator; see Figure 58.                       |

TABLE 8

Recording Accelerometers for Measurement of Transient Vibration

| Name                                          | Practical Frequency Range<br>CPS                   | Practical Single Amplitude Range<br>g                                           | Sensitivity                                  | Direction of Vibration | Method of Detection                          | Method of Recording   | Method of Damping                                 |
|-----------------------------------------------|----------------------------------------------------|---------------------------------------------------------------------------------|----------------------------------------------|------------------------|----------------------------------------------|-----------------------|---------------------------------------------------|
| Brush VP-5 crystal acceleration pickup        | 10 to 500                                          | 0.001 to 10                                                                     | About 80 mv RMS per g                        | Any one                | Piezoelectric crystal                        | Oscillo-graphic       | None                                              |
| BuOrd torpedo accelerometer                   | 0 to 30                                            | 0.25 to 25                                                                      | 0.04 in. per g on record                     | Any one                | Spring-mounted mass, mechanical lever        | Stylus on waxed paper | Oil, not adjustable                               |
| Single damped-cantilever accelerometer        | 0 to 50                                            | 0.1 to 18                                                                       | 22.5 mv per g per 45 volts applied           | Any one                | Metaelectric strain gage                     | Oscillo-graphic       | Oil film between parallel plates, adjustable      |
| Double cantilever accelerometer, Types A to E | 10 to 800                                          | 1 to 2000, estimated                                                            | About 45 mv per g per 45 volts applied       | Any one                | Metaelectric strain gages                    | Oscillo-graphic       | Very little, internal damping of plastic material |
| Metaelectric accelerometer                    | 10 to 5000                                         | 10 to 5000, estimated                                                           | 0.185 mv per g per volt applied              | Any one                | Weighted cylinder, metaelectric strain gages | Oscillo-graphic       | None                                              |
| Consolidated accelerometer                    | 0 to 35                                            | 0.02 to 15                                                                      | 25 mv per g with 15-volt carrier             | Any one                | Seismic inductance, variable reluctance      | Oscillo-graphic       | Magnetic                                          |
| Pallograph-type accelerometer                 | 0 to 1                                             | 0.001 to 0.08                                                                   | On record, inches per g                      | Vertical only          | Spring-mounted weight, mechanical lever      | Stylus on waxed paper | Air dashpot, adjustable                           |
| Group I**                                     | 0 to 1<br>0 to 1.5<br>0 to 2<br>0 to 2.5<br>0 to 3 | 0.002 to 0.16<br>0.004 to 0.34<br>0.007 to 0.63<br>0.013 to 1.0<br>0.016 to 1.0 | 5.76<br>2.63<br>1.33<br>0.71<br>0.35<br>0.28 |                        |                                              |                       |                                                   |
| Group II**                                    | 0 to 2<br>0 to 3<br>0 to 4<br>0 to 5<br>0 to 6     | 0.03 to 1.2<br>0.05 to 2.0<br>0.10 to 4.3<br>0.15 to 6.8<br>0.20 to 9.0         | 0.33<br>0.20<br>0.10<br>0.066<br>0.05        | Any one                |                                              |                       |                                                   |

TABLE 8 (continued)

| Natural Frequency of Element CPS             | Weight pounds | Overall Dimensions (LxWxH) or (DxH) inches | Power Required | Accessory Equipment Required                 | Method of Mounting on Vibrating Structure             | Figure Number | Remarks                                                                 |
|----------------------------------------------|---------------|--------------------------------------------|----------------|----------------------------------------------|-------------------------------------------------------|---------------|-------------------------------------------------------------------------|
| 1500                                         | 0.4           | 3 x 2                                      | 110-v a.c.     | Usual electronic equipment*                  | Held against or clamped to structure                  | 8             |                                                                         |
| 35                                           | 7 3/4         | 5 x 10                                     | 6-v dry cell   | Timer, if desired                            | Bolted or clamped to structure                        | 7             | Holds maximum of 40 inches of paper which permits 30 seconds of record. |
| 215                                          | 4.2           | 4 1/2 x 2 x 6                              | 110-v a.c.     | Usual electronic equipment*                  | Bolted or clamped to structure                        | 9             | Development inactive.                                                   |
| 200<br>1400<br>1800<br>2400<br>3500          | Type D, 1.0   | Type D<br>8 x 2 1/2 x 2                    | 110-v a.c.     | Battery box and usual electronic equipment*  | Bolted or clamped to structure                        | 10            |                                                                         |
| 15,000                                       | 1/2           | 1 1/2 x 1 1/2 x 2                          | 100-v a.c.     | Battery box and usual electronic equipment*  | Screwed to 5/8-inch stud which is welded to structure | 59            |                                                                         |
|                                              | 0.8           | 2 3/4 x 2 1/2 x 2 3/4                      | 110-v a.c.     | 1000-CPS bridge, usual electronic equipment* | Bolted or clamped to structure                        | 14            |                                                                         |
| 2.16<br>2.76<br>3.83<br>5.35<br>6.79<br>7.48 | 40            | 20 x 8 x 14                                | 110-v a.c.     | Synchronous timer                            | Bolted or clamped to structure                        | 13            | Adapted from Type B pallograph.                                         |
| 5.42<br>7.00<br>9.9<br>12.1<br>14.0          |               |                                            |                |                                              |                                                       |               | Uses special weight and two-spring suspension.                          |

TABLE 8 (continued)

| Name                                                                                                                                                                                            | Practical Frequency Range<br>CPS | Practical Single Amplitude Range<br>g | Sensitivity                           | Direction of Vibration   | Method of Detection                                      | Method of Recording | Method of Damping    |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|---------------------------------------|---------------------------------------|--------------------------|----------------------------------------------------------|---------------------|----------------------|
| Statham accelerometer R-500-700                                                                                                                                                                 | 0 to 850                         | 1 to 500                              | About $1/5$ mv per g (max)            | Any one normal to base   | Strain wires forming bridge circuit support inertia mass | Oscillographic      | Organo-silicon fluid |
| Statham accelerometer Ar-12V-250                                                                                                                                                                | 0 to 150                         | 0.1 to 12                             | About 3 mv per g (max)                | Any one normal to base   | Strain wires forming bridge circuit support inertia mass | Oscillographic      | Organo-silicon fluid |
| Statham accelerometer S-1.5-120                                                                                                                                                                 | 0 to 60                          | 0.01 to 1.5                           | About 10 mv per g (max)               | Any one parallel to base | Strain wires forming bridge circuit support inertia mass | Oscillographic      | Organo-silicon fluid |
| Westinghouse crystal accelerometer                                                                                                                                                              | 10 to 5000                       | 10 to 5000                            | $0.62 \times 10^{-12}$ coulombs per g | Any one                  | Piezoelectric crystal                                    | Oscillographic      | None                 |
| TMB crystal accelerometer, single-faced                                                                                                                                                         | 10 to 5000                       | 10 to 5000                            | $0.77 \times 10^{-12}$ coulombs per g | Any one                  | Piezoelectric crystal                                    | Oscillographic      | None                 |
| TMB crystal accelerometer, push-pull                                                                                                                                                            | 10 to 5000                       | 10 to 5000                            | $0.77 \times 10^{-12}$ coulombs per g | Any one                  | Piezoelectric crystal                                    | Oscillographic      | None                 |
| * Usual electronic equipment consists of amplifier and power supply; Variac transformer and regulator; oscillator and microvolter; cathode-ray oscillograph and camera, or string oscillograph. |                                  |                                       |                                       |                          |                                                          |                     |                      |

TABLE 8 (continued)

| Natural Frequency of Element CPS                                                                                                                                                     | Weight pounds | Overall Dimensions (LxWxH) or (DxH) inches | Power Required    | Accessory Equipment Required                                     | Method of Mounting on Vibrating Structure | Figure Number | Remarks |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|--------------------------------------------|-------------------|------------------------------------------------------------------|-------------------------------------------|---------------|---------|
| 1670                                                                                                                                                                                 | 0.5           | 2 x 1 1/4 x 2 1/2                          | 20-v d.c. (max)   | 5-KC carrier, power supply, oscillograph                         | Bolted to structure (5-40 screws)         | 17            |         |
| 300                                                                                                                                                                                  | 0.5           | 2 x 1 1/4 x 2 1/2                          | 12.5-v d.c. (max) | Modified TMB 1-A strain amplifier                                | Bolted to structure (5-40 screws)         | 17            |         |
| 115                                                                                                                                                                                  | 0.8           | 2 3/8 x 1 3/4 x 2 3/8                      | 5-v d.c. (max)    | Usual electronic equipment* or modified TMB 1-A strain amplifier | Bolted to structure (5-40 screws)         | 17            |         |
| 15,000                                                                                                                                                                               | 0.6           | 1 x 2                                      | 110-v a.c.        | Usual electronic filter                                          | Screwed to 1/2"-13 stud                   | 60            |         |
| 15,000                                                                                                                                                                               | 0.6           | 1 x 2                                      | 110-v a.c.        | Usual electronic filter                                          | Screwed to 1/2"-13 stud                   | 60            |         |
| 15,000                                                                                                                                                                               | 0.6           | 1 x 2                                      | 110-v a.c.        | Usual electronic filter                                          | Screwed to 1/2"-13 stud                   | 60            |         |
| ** The springs listed in Group I replace the pallograph displacement spring. The springs listed in Group II are used with a special weight and two-spring suspension; see Figure 13. |               |                                            |                   |                                                                  |                                           |               |         |



## A DEVICE FOR MECHANICAL TEST OF ELECTRONIC EQUIPMENT

O. Norgorden and F. J. Shanahan, NRL

*Vib-Roll-Shocker* is the descriptive name for a device used in studying the mechanical strength factors of various electronic equipments by subjecting them to controlled vibration, roll, and shock. Observations are also made of the effects of such tests upon the electrical characteristics of the electronic equipment.

The objective of the designers was to provide as wide a latitude as practical in the characteristics of the device so that it might serve not only immediate needs, but that it might also have a reasonable chance of filling the future needs as more information becomes available on shock and vibration conditions on board ship. The most important immediate need was for the development of a system by means of which complete electronic equipments weighing up to 3500 lb could be mounted, placed in operation, and subjected to mechanical tests in order to determine the suitability of such equipment for naval service. The system was designed at NRL by personnel of the Communication Section and Messrs. O. C. Dresser and C. R. Shuler of the Design and Drafting Section, was manufactured at the Navy Shipbuilding Yard, New York, N.Y., and is now installed at NRL.

Since total test time was considered an important factor, and since many hours are required to make the necessary electrical connections to the equipments being tested, it was decided to combine the three functions of vibration, roll, and shock in a single device, if this were at all practical. The time saved in making electrical connections in some of the more complex electronic equipment and in eliminating hidden defects may amount to several days. Another advantage in having a composite device is the ability to repeat tests at any time without requiring additional set-up time.

The ability to impart vibration and roll simultaneously is still another advantage.

The disadvantages of a composite device are the limitations which are imposed upon the design. It was evident that the incorporation of vibration along more than one axis, or shock in more than one plane, would not be practical without eliminating the roll function. Electronic equipments are complex mechanical structures, and the electrical components are coupled to the frame and the deck or bulkhead mountings through a complicated linkage system. Thus, it is reasonable to assume that each element or component in the equipment will be excited and will vibrate in its natural mode even though the axis of vibration is at right angles to the primary exciting force. It was realized that vibration along only one axis would not completely duplicate shipboard conditions; however, vertical vibration should provide adequate means for determining the probable action of larger deck-mounted equipments under conditions of steady-state vibration as encountered on board ship. It is usually possible to rig bulkhead-mounted equipment in such a manner that a satisfactory simulation of shipboard conditions is realized.

The following general specifications were adopted:

1. Size of test platform - 77 x 77 in.
2. Maximum test load - 3500 lb .
3. Vibration:
  - (a) Type - direct drive
  - (b) Amplitude -0.000 to 0.093 in
  - (c) Frequency - 1 to 35 cycles per second
  - (d) Acceleration (maximum)-3 g
  - (e) Maximum variation of amplitude with frequency - 10%

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#### 4. Roll:

- (a) Amplitudes -  $22.5^{\circ}$ ,  $30^{\circ}$ ,  $37.5^{\circ}$ , or  $45^{\circ}$ , in both directions from vertical plane and about a horizontal axis
- (b) Frequency - 5 to 10 cycles per minute

#### 5. Shock:

- (a) Type - pneumatic ram
- (b) Velocity - 3 to 9 ft/sec
- (c) Acceleration - from 10 g to 750 g
- (d) Displacement - 3 in. maximum
- (e) Duration of Shock - variable from 100 microseconds to 10 milliseconds

A pictorial diagram of the *Vib-Roll-Shocker* is shown in Figure 1. Figures 2 and 3 are detailed pictorial diagrams of the vibration drive and shocker mechanisms. The *Vib-Roll-Shocker* is mounted on a concrete slab in a pit so that the top of the turntable is level with the floor. The device weighs about 13 tons, and the concrete slab weighs about 40 tons.

The major components of this device are (Figure 1):

1. Base (part No. 1), which is a 40-ton slab of concrete.
2. Main frame (part No. 2), which supports all of the other components.
3. One-ton turntable (part No. 3), upon which the equipment under investigation is mounted.
4. Pedestal (part No. 4) and vibration frame (part No. 5), upon which the turntable rests and is bolted for vibration and roll tests.
5. Vibration drive motor (part No. 6) and the associated vibration drive mechanism parts.
6. Roll frame (part No. 7) and its associated trunnion bearings (part No. 3). This frame supports the vibration drive mechanism, the vibration frame and the turntable.

7. Roll drive motor (part No. 9) and its associated crank and linkage drive mechanism (part No. 10).

8. Pneumatic ram (part No. 11).

#### ROLL

For the roll tests the turntable (part No. 3) is bolted to the vibration frame. The roll frame (part No. 7) oscillates on trunnion bearings. This frame supports the vibration frame and vibration mechanism. Counterbalancing weights (part No. 12) are attached to the under side of the roll frame. The 1000-pound counterweights may be adjusted from 1.5 ft to 4.5 ft below the roll axis and are capable of counterbalancing the roll unit for all normal loads. A 7.5-hp motor provides the drive for the roll unit through a reduction gear, arm, and crank mechanism. The design permits roll angles of  $22.5^{\circ}$ ,  $30^{\circ}$ ,  $37.5^{\circ}$  and  $45^{\circ}$  degrees, and the rolling frequency is continuously variable from 5 to 10 cycles per minute. The turntable can be rotated through  $90^{\circ}$ , which is equivalent to rotating the roll axis  $90^{\circ}$  in the horizontal plane.

#### VIBRATION

The turntable is bolted to the vibration frame for the vibration tests. The vibration frame is confined to motion along the vertical axis by guides on the roll frame. Direct drive is provided at four points of the vibration frame by four vibration drive mechanisms (part No. 13) mounted on the roll frame (see Figure 1). The mechanical details of the vibration drive mechanisms are shown in Figure 2. A 20-hp variable-speed motor (part No. 6 in Figure 1) is the prime mover for the vibration drive mechanism, and the power is transmitted by a line shaft concentric with the trunnion bearings of the roll frame. Silent chains are used (part No. 14 of Figure 1) to drive the four double eccentric units and thus provide in-phase vibration to the

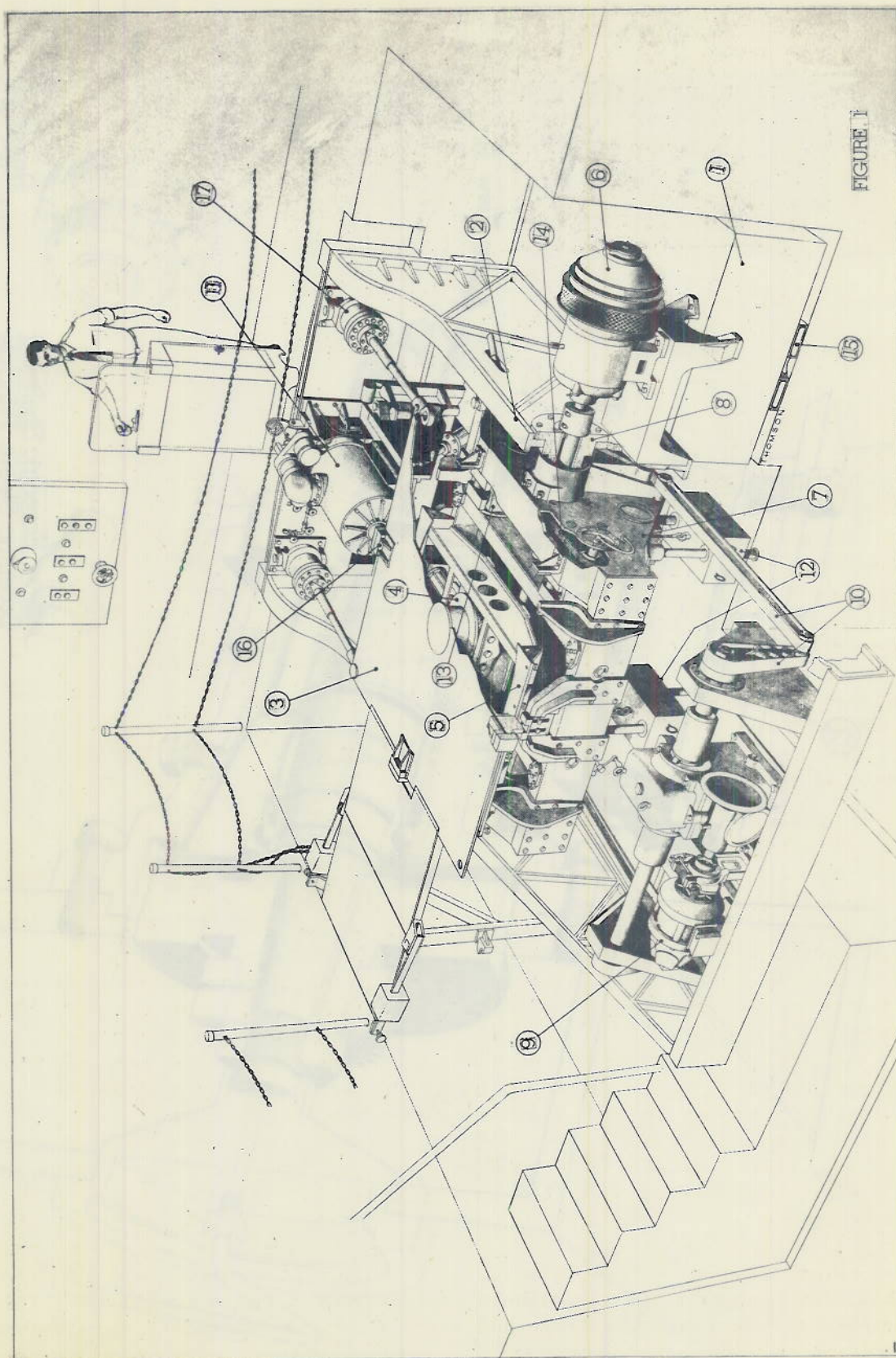


FIGURE 1

Figure 1

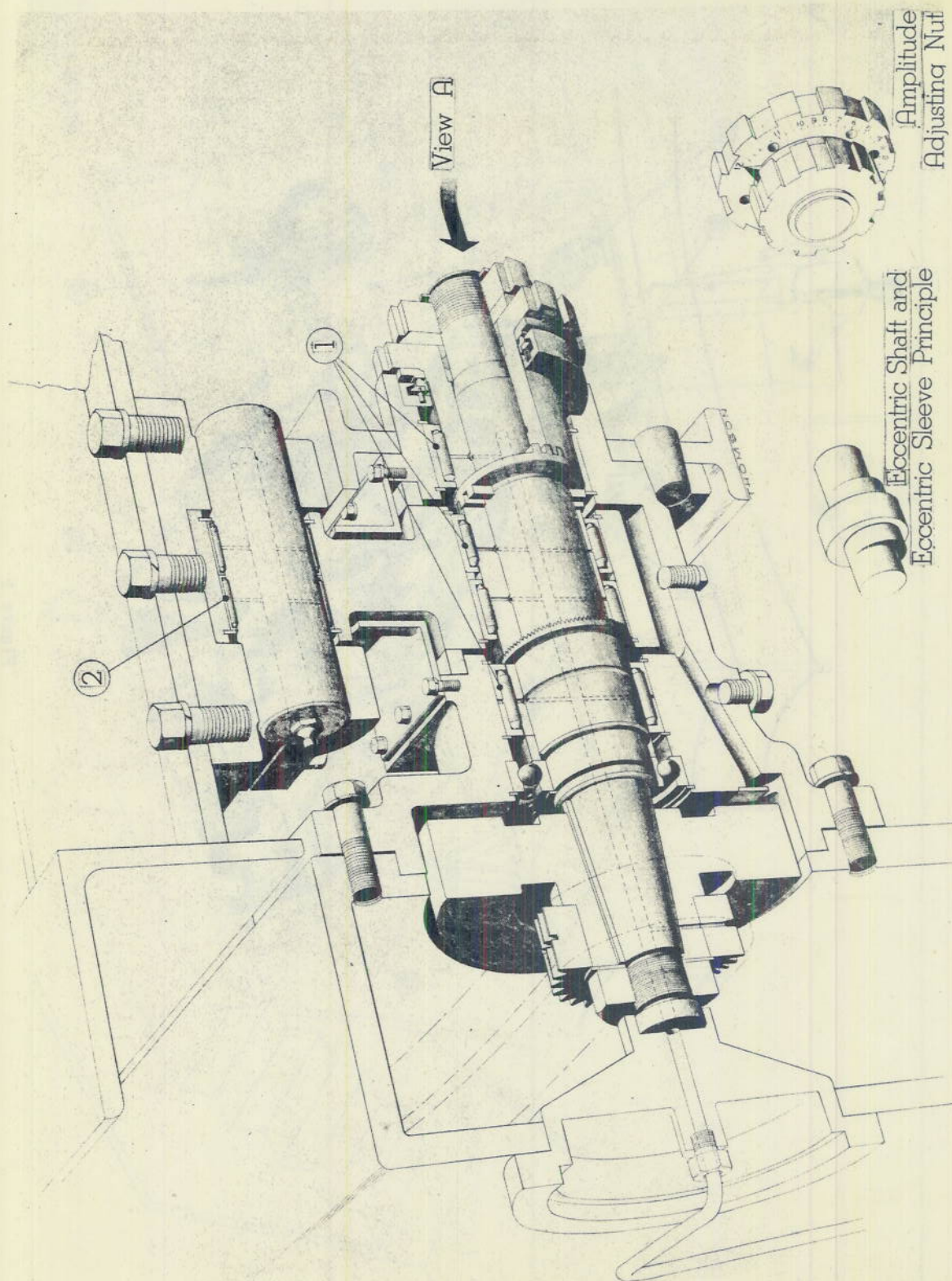


Figure 2

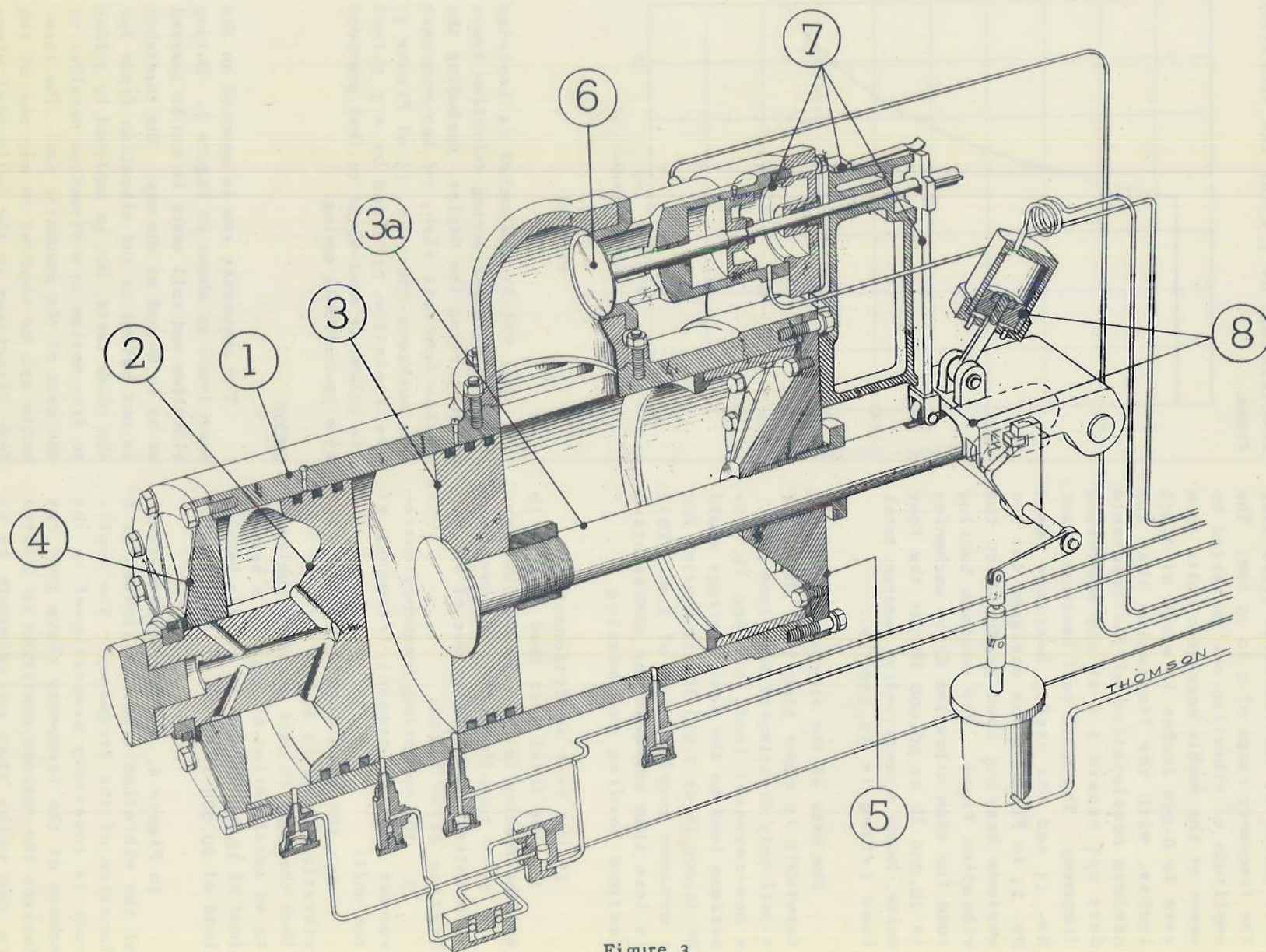


Figure 3

four points of the vibration frame over the frequency range of 0 to 35 cps. The amplitude of vibration can be varied by means of the double eccentric units from zero to 0.094 inches in steps of 0.002 inches, with the limitation that the maximum acceleration of the turntable does not exceed 3 g at any operating frequency. The small roll bearings (part No. 1) and the needle bearings (part No. 2) in Figure 2 are designed for the maximum bearing load produced by the vibration frame. The maximum bearing load for each vibration drive mechanism is 20,000 lb or 80,000 lb for the four units, hence a conservative maximum total load rating is 60,000 lb.

The mass of the vibration frame and turntable is about 3500 lb. Thus, for a uniformly distributed dead load (i.e., a non-resonant load) of 3500 lb, the maximum load on the four bearings would be 28,000 lb or 7,000 lb per bearing for a maximum acceleration of 3 g. This is less than one-half the conservative maximum loading per bearing.

If the test conditions are:

1. the total test load is 3500 lb and the loading is approximately uniform;
  2. a 1000-lb unit of this test load is mounted directly over one of the vibration drive units;
  3. the operating frequency corresponds to the resonant frequency of the unit;
  4. the peak acceleration of the vibration frame is 3 g;
- then the 1000-lb unit could be subjected to an acceleration of 8 g for a bearing load of 15,000 lb, and 14 g for a bearing load of 20,000 lb.

In Figure 4, the maximum amplitude of the vibration frame is plotted as a function of the frequency. The amplitude is inversely proportional to the square of the frequency above 17.7 cps because the maximum amplitude is limited to the value that corresponds to an

acceleration of 3 g for the vibration frame.

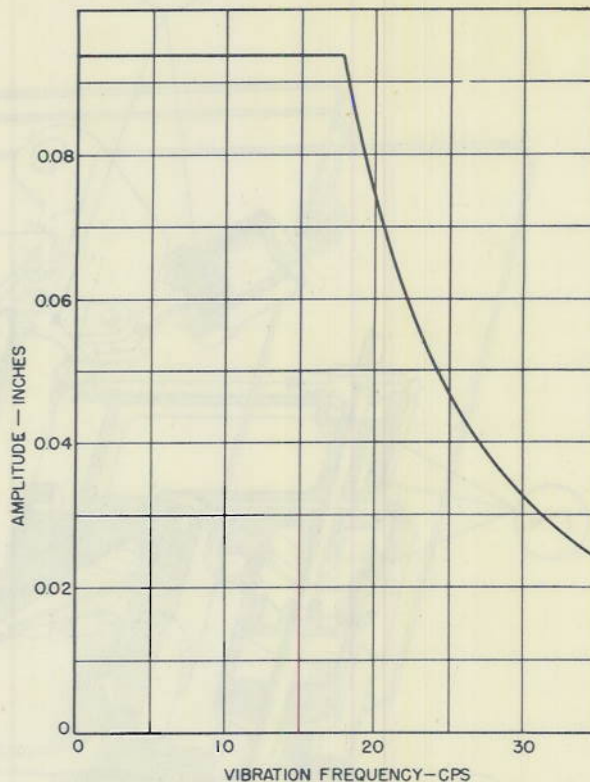


Figure 4

The *Vib-Roll-Shocker* is isolated from the building during vibration tests by supporting the device, including the 40-ton concrete slab, on low-pressure air cushions (part No. 15 of Figure 2). The isolation provided by a 1.5-inch air column is equivalent to that provided by a 12-inch coil spring.

#### SHOCK

The pneumatic ram is mounted on the main frame as shown in Figure 1. During vibration and roll tests it can be lowered so as to be out of the way. The turntable is not bolted to the vibration frame for the shock tests, but is confined by guides to free motion in a direction parallel to the axis of the pneumatic ram. The turntable can be shocked in any one of the four directions in the horizontal plane

by simply rotating the turntable. The shock is transmitted from the pneumatic ram to the turntable through any one of the four anvils (part No. 16 of Figure 1).

The aim in designing the pneumatic ram was to provide a device capable of shocking electronic equipment through the design range of peak velocity and over a range of peak accelerations at any given peak velocity. The peak velocity is the maximum velocity imparted to the turntable during a shock cycle. This device is capable of producing, within a limited range, shocks of long or short duration.

The pneumatic shock device is shown in greater detail in Figure 3. It consists of a cylinder (part No. 1), an anvil piston 15 inches in diameter (part No. 2), a shocking piston (part No. 3) and its associated shaft (part No. 3A), a front end plate (part No. 4), a rear end plate (part No. 5), an exhaust valve (part No. 6), an exhaust-valve-closing and preloading mechanism (part No. 7), and a latching mechanism (part No. 8). Figure 3 shows the various parts of the device in the cocked position ready for charging and firing. The heavy shaft of the anvil piston (part No. 2) is held in positive contact with the anvil on the turntable previous to and during the shock interval. The initial distance between the pistons is 4 inches, and the air column back of the shocking piston is 16 inches.

A short description of the shock cycle will lead to a better understanding of the device. The air between the shocking piston (part No. 3) and the rear end plate (part No. 5) is at a pressure  $P_1$  when the device is in the cocked position. The pressure  $P_2$  between the two pistons can be controlled by the operator previous to firing. In this example, the pressures  $P_1$  and  $P_2$  are assumed to be 194.7 and 14.7 psi respectively. For normal test conditions the pressure  $P_1$  is large compared to the pressure  $P_2$ . Immediately

after the shocking piston is released by the latching mechanism, a force of about 30,000 lb accelerates the shocking piston. The energy expended by the air at pressure  $P_1$  is converted into kinetic energy in the shocking piston, potential energy in the gas between the two pistons, and kinetic energy in the anvil piston and turntable. Since the initial pressure  $P_2$  is small compared to  $P_1$ , practically all of the energy expended by the air at pressure  $P_1$  will be converted into kinetic energy in the shocking piston, provided the shocking piston is not too close to the forward end of the stroke. As the shocking piston approaches the forward end of the stroke, the pressure between the two pistons increases rapidly and attains a peak pressure of about 4150 psi. The kinetic energy imparted to the anvil piston and turntable is small up to the time the pressure between the two pistons is a maximum, because their combined mass is about ten times that of the shocking piston. The maximum pressure of 4150 psi corresponds to a maximum force of 730,000 lb, a maximum acceleration of the shocking piston of 3200 g, and a maximum acceleration of the anvil piston and turntable of 320 g.

The potential energy of the gas between the two pistons is expended by accelerating the shocking and anvil pistons. The maximum velocity of the anvil piston and turntable is about 9.1 ft/sec after the shock. This maximum velocity is attained before the anvil piston moves 0.25 inches from its initial position. The duration of the shock is defined as the time interval when the acceleration of the anvil piston and turntable is greater than 50% of its maximum value, and is 0.6 milliseconds for this example.

The hydraulic shock absorbers (part No. 17 in Figure 1) permit essentially free motion of the anvil piston and turntable for the first inch of motion, and

then retard and stop the turntable in the next 2.5 inches.

If the air at pressure  $P_1$  is not released by the end of the shock cycle, the striking piston will oscillate and produce several secondary shocks. The latching mechanism (part No. 8 in Figure 3) releases the 5-inch diameter exhaust valve (part No. 6) near the end of the forward stroke of the shocking piston. The exhaust valve is opened rapidly by the exhaust-valve-closing and pre-loading mechanism (part No. 7). The energy in the air at pressure  $P_1$  is then essentially expended before a secondary shock can occur.

If one increases the initial pressure  $P_2$  between the two pistons, the pressure and the potential energy between the two pistons will increase more rapidly with the forward motion of the shocking piston. Thus, the maximum pressure between the two pistons and the peak acceleration will be decreased, but the duration of the shock will be increased, and by controlling the pressure  $P_2$  of the gas between the two pistons as well as the air pressure  $P_1$  in back of the shocking piston  $P_1$ , one can control the maximum velocity after the shock and the peak acceleration during the shock.

The curves in Figure 5 give the velocity and the acceleration of the anvil piston and turntable as a function of the time for two operating conditions. The maximum velocity is about 9.3 ft/sec in both cases. The operating pressure  $P_1$  is about 200 psi for all the curves and the pressure  $P_2$  is 14.7 psi for the solid curves and 30 psi for the dashed curves. The maximum acceleration in one case is about 320 g and in the other case is about 120 g. It should be noted that for the lower-peak-acceleration case, the shock interval is longer and the velocity builds up more slowly than for the other conditions.

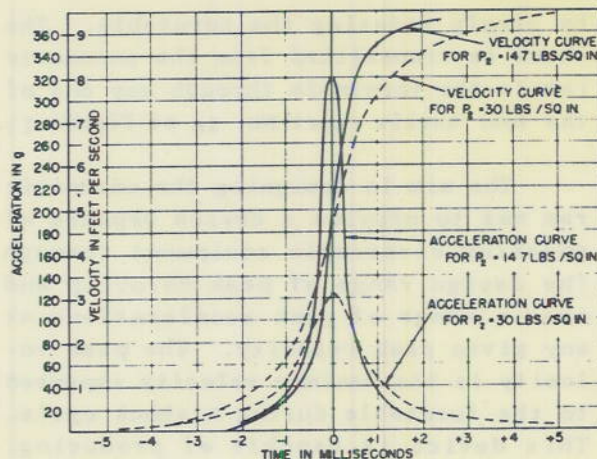


Figure 5

In the present design of the pneumatic ram, the maximum velocity of the turntable can be varied from about 3 to 9 ft/sec, and the maximum acceleration at any given velocity can be varied over a range of about 10 to 1 except for the highest and lowest velocities. The maximum force for which the anvil piston and turntable are designed is about 1,500,000 lb. This corresponds to a maximum acceleration of about 700 g. The practicable minimum acceleration produced by the device is about 10 g.

The pressures  $P_1$  and  $P_2$  necessary to produce any desired values of peak velocity and peak acceleration within the operating range may be determined from Figure 6 for an unloaded turntable. There are two sets of velocity curves. The upper set of constant velocity curves gives the range of peak acceleration as a function of the operating pressure  $P_1$ . The lower set of instant velocity curves give the pressure  $P_2$  as a function of the operating pressure  $P_1$ .

The method of using these curves is illustrated by an example. If a shock with a peak velocity of 5 ft/sec is desired, then on the upper 6 ft/sec velocity curve a peak acceleration of 100 g

corresponds to a pressure  $P_1$  of 87 psi.  
On the lower 6 ft/sec velocity curve an

operating pressure  $P_1$  of 87 psi requires  
a pressure  $P_2$  of 7.4 psi.

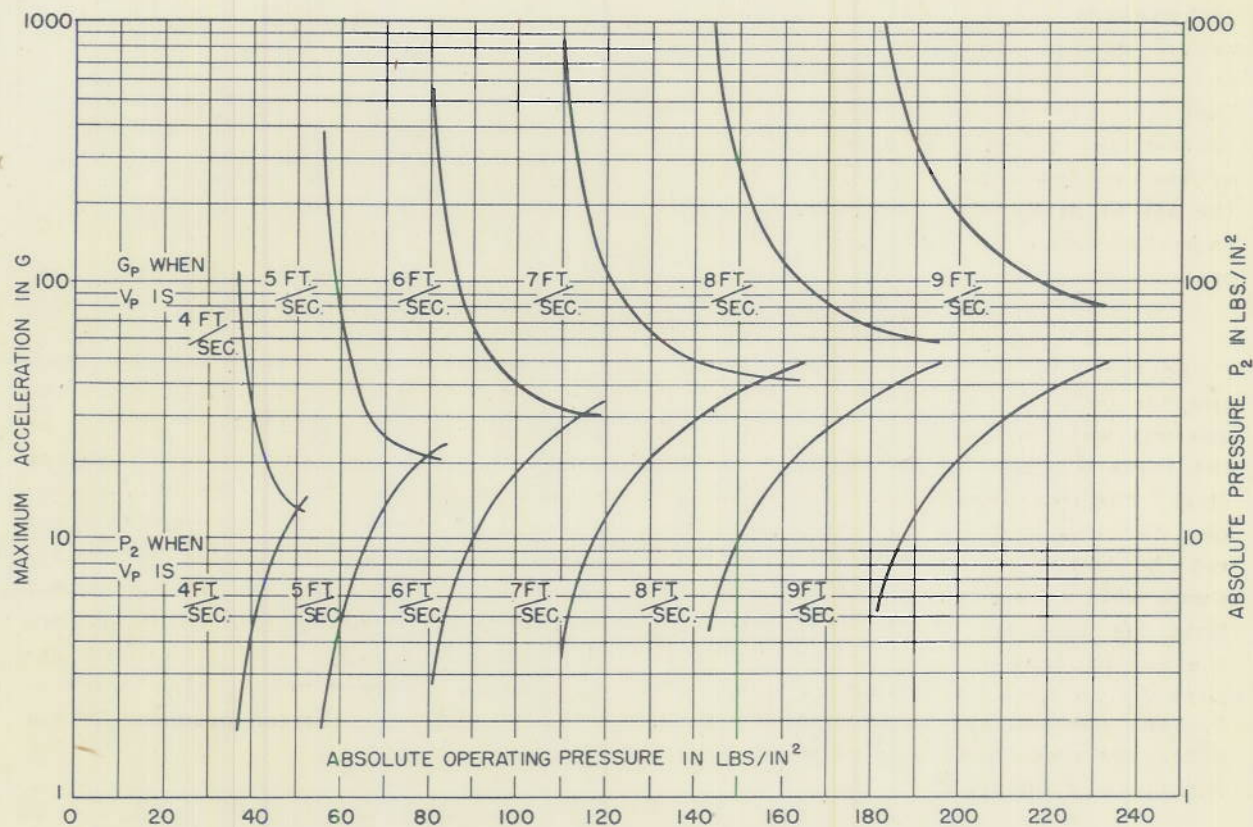


Figure 6



## SAVIBULL

## MINUTES OF SHOCK AND VIBRATION TERMINOLOGY AND STANDARDS COMMITTEE MEETING HELD ON 11 MARCH 1947.

The meeting was held at the Navy Department, Building W, from 1:30 to 3:15 P. M. The following members of the Committee were present:

J. O. Baker - DTMB  
 Leslie W. Ball - NOL  
 L. H. Fryer - BuShips  
 D. E. Goldman - NMRI  
 Myles Maxfield - NMRI  
 H. M. Trent - NRL  
 Bernard A. Wiener - BuAero

The first subject discussed was the type of organization that would be most appropriate to the Committee's objectives. It was agreed that these objectives were:

(a) To establish a terminology that would facilitate the understanding by the staffs of all the represented agencies of technical papers, equipment specifications, and technical data in the field of shock and vibration.

(b) To help evolve an integration of the work of the Naval facilities with that of outside groups in industry, universities, etc., by encouraging the use of the same terms and methods of presentation of data, or by securing recognition of unchangeable differences in terminology.

(c) To review and record acceptable methods of measurement of all the pertinent parameters of shock and vibration equipment and investigations.

The proposed method of operation to achieve the above objectives was as follows: the Committee would meet about one

week before each scheduled meeting of the shock and vibration symposia and about once a month thereafter until a skeleton terminology and list of acceptable tests and measurement methods had been established. Subsequently, meetings would be held to consider specific proposals for additions to or changes in the established terminology.

To pursue the principle that a very small group should create written proposals for review by the more representative committee, it was agreed that individuals would be assigned the task of preparing proposals on specific items. At the main symposia requests will be made for volunteers on such assignments from the main group. It was agreed that the complete terminology, to be evolved by the Committee would be divided into three sections and that some overlap between these sections would not be objectionable.

The first section would be qualitative terms such as "shock effect". The second section would be mathematical definitions and would include recommended graphical methods for the presentation of data as well as an aid to definition of terms. The third section would be standard measurements and would include the definition of the quantity in terms of an acceptable method of measurement and would include a description of such acceptable methods.

*Leslie W. Ball, Secretary*

## FUTURE SYMPOSIA

Tentative arrangements have been made for a symposium on 25 June 1947. The program consists of:

a. Summary of shipboard shock measurements as a result of underwater explosions

and air blasts (by DTMB),

b. Summary of the tests on HMS CAMERON (by NRL)

c. Summary of contact and near contact explosions on models (by BuShips).

Probable topics for a symposium in September 1947 are:

a. The characteristic shock problems peculiar to ordnance.

b. Shock and vibration preventive measures in ordnance weapons.

For November 1947:

Characteristic shock problems peculiar to aircraft and land vehicles.

For later:

Survey of existing methods and means for standardizing shock and vibration instruments for use in the field and in the laboratory.

Present knowledge of the internal characteristics of materials as related to their impact and shock resistance.

#### Notice

It is proposed to submit in advance a brief outline of each talk so that discussions and questions regarding the various topics may be prepared before the corresponding meeting takes place.