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New Instrumentation for Vibration Testing

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Interchangeable Head Vibration Exciters*)

by

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ABSTRACT

A new electromagnetic vibration exciter design, in which the entire dynamic portion of the vibration exciter can be quickly changed, provides optimization of vibration exciter performance characteristics for specific applications. Since a head with the performance characteristics needed for the job can be selected, it is no longer necessary to use a compromise vibration exciter design. The performance characteristics discussed include those applicable to 200 g testing, the testing of large objects where high side load capability and a rigid table are essential, the measurement of structural modes, impedances, and transfer functions and confirmation calibration of accelerometers and other transducers. The design objectives and solutions are presented for the stiff, highly damped suspension systems that make interchangable heads possible. The moving element skeletons of five different heads are described in detail, showing how the different performance criteria for various applications are achieved. Included in the program are three different vibration exciter sizes with four or five heads for each.

SOMMAIRE

La conception d'excitateurs électromagnétiques de vibration dont l'élément mobile peut être rapidement changé, permet d'avoir des performances optimales en fonction d'applications particulières. Etant donné qu'il est prévu une tête spécifique à un travail donné, il n'a pas été nécessaire d'envisager de solution de compromis dans la conception de l'excitateur. Les caractéristiques qui sont étudiées ici concernent les essais à 200 g, l'essai d'objets volumineux, l'étude des modes propres, la mesure des impédances mécaniques et des fonctions de transfert, et la vérification de l'étalonnage des accéléromètres et autres traducteurs. Nous montrons ici comment ont été étudiés les systèmes raides et fortement amortis qui rendent possibles l'emploi des parties mobiles interchangeables. Les éléments constitutifs de cinq têtes différentes sont décrits en détail et les performances particulières à chaque application sont étudiées. Le programme complet comprend trois excitateurs de taille différente susceptible de recevoir chacun quatre ou cinq types de partie mobile.

ZUSAMMENFASSUNG

Ein neuer Entwurf von elektromagnetischen Schwingerregern, bei dem das gesamte dynamische System schnell umgewechselt werden kann, sorgt für die Optimierung der charakteristischen Wandlereigenschaften für spezifische Anwendungen. Weil ein System mit den für die jeweilige Aufgabe notwendigen Wandlereigenschaften ausgewählt werden kann, ist nicht länger die Verwendung einer Kompromiß-Konstruktion nötig. Die besprochenen charakteristischen Wandlereigenschaften umfassen solche, wie sie für 200 g-Tests anwendbar sind, für Prüfungen großer Objekte, wo große Querkräfte aufgefangen werden müssen und eine steife Aufspannfläche wesentlich sind, Charakteristiken passend für die Messung von Eigenschwingungsformen, von Impedanzen und Übertragungsfunktionen und schließlich für den "Confirmation"-Test, den Nachweis über

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den Linearitätsbereich der Eichung von Schwingungsaufnehmern und anderen Wandlern. Die Entwicklungsziele und -lösungen werden vorgestellt für die steifen, stark gedämpften Rückstellfederungen, die umtauschbare dynamische Systeme möglich machen. Die Skelette von 5 verschiedenen Tauchspulsystemen werden in Einzelheiten beschrieben; dabei wird gezeigt, wie die Wandlereigenarten für verschiedene Anwendungen zustande gebracht werden. Im Programm sind drei Schwingerreger unterschiedlicher Größe mit je vier oder fünf verschiedenen Arbeitsköpfen enthalten.

Introduction

An Interchangeable Head Vibration Exciter has two parts, an Exciter Head and an Exciter Body. In the Exciter Head are all of the dynamic parts of the vibration exciter, those parts that adapt the exciter to a particular range of applications. All of the general purpose parts of the exciter are in the Exciter Body, including the magnetic iron structure and the pedestal.

The program includes three sizes of vibration exciters, with four or five heads for each size. The heads of the smallest size, size V, have force ratings of 85 and 100 pounds, 380 and 445 newtons. The heads of the next larger size, size S, have force ratings of 325 and 400 pounds, 1445 and 1780 newtons. The heads of the largest size, size M, have force ratings of 1200 and 1500 pounds, 5340 and 6670 newtons.

Four types of heads exist for each of the sizes: The High G Head, the General Purpose Head, the Big Table Head, and the Mode Study Head. A fifth head, the Calibrator Head, is available only in the V size. The design of each of these heads is slanted to favor a particular range of applications.

Why Interchangeable Heads?

Vibration exciters are used in many applications. These many applications require quite different things of the vibration exciter.

Heretofore, most of the better vibration exciters have tended to be compromise designs. The designer has reviewed the conflicting needs of the various applications and has attempted to find a compromise design that was satisfactory for all.

Unfortunately, the requirements are so conflicting that the resulting compromise designs are not really adequate. It is the dissatisfaction with these compromise designs which lead to the development of the interchangeable head concept.

By providing four or five different heads for each size vibration exciter, it is possible to come very close to the requirements of each of these many applications. A head may be selected for a particular application with minimum compromise.

Since any user usually has many different applications from time-to-time, he can change his vibration exciter to suit the application merely by changing heads. Since it is easy to switch to the right head for the job, the user is more likely to get good data and less likely to improperly damage a tested object. The use of the proper head for the task is analogous to "Use the right size wrench for the bolt".

As an example, consider the vibration testing of a large object. If the object is large, the user must be very careful to adequately attach the object to the table before testing it to make sure that any damage occurring during testing is due to the vibration applied to the object, and not a result of bending it. Also, since this large object will have parts that tend to vibrate in many directions, it will require strong guidance if reasonably rectilinear motion is to be achieved. A large, rigid table and a very strong moving element suspension system are needed to restrain undesired motions and to support the weight of the object during horizontal testing. The Big Table Head is designed to satisfy these requirements.

A contrasting example is the vibration testing of an object at high acceleration levels. To be within the force capabilities of the machine, the object is small and light weight. A large mounting surface is not needed, but it is very important that the weight of the moving element be minimized, since excessive moving element weight subtracts from the available payload. The High G Head is designed to meet these requirements.

A quite different set of requirements is required when a vibration exciter is used to vibrate structures or models of structures to determine their responses. Since the output force is usually coupled by a push rod, no table is required. A reasonably large available motion between stops is important to make the adjustment of the push-rod length less critical and allow for large low frequency displacements. The suspension system must be strong to resist side forces from the push rod. The characteristics of the Mode Study Head are optimized to meet these requirements.

Different again are the requirements for a confirmation calibrator. Rather than risk damage to a very valuable test object, many laboratories routinely confirm the calibration of every accelerometer at a level equal to or higher than the level at which it is to be used, just prior to the test. Since the levels the response measuring accelerometers will see are unknown, an arbitrary confirmation level is selected, 100 g being the common level. A built in reference accelerometer, high resonant frequency, and low cross motion are other requirements. The Calibrator Head of the V size is designed to meet these requirements.

An entirely different use for the interchangable head feature exists in the busy test laboratory. It is a common experience that setting up a test on a vibration exciter and de-bugging all of the instrumentation attached to the object to be tested frequently takes much longer than the test, especially since many tests are terminated prematurely. The use of two or more Exciter Heads with each Exciter Body can greatly increase the output of such a laboratory since set up and de-bugging can take place on one head while another is in use on the Exciter Body.

Exciter Body Construction
There are three sizes of Interchangable Head Vibration Exciters, V, S and M. The illustrations in this paper are primarily of the S size. Since the S is

Figure 1. S Exciter Body

intermediate in size between the smaller V and the larger M, the illustrations show typical features of all three sizes. The discussion is applicable to all three sizes.

The Exciter Body is shown without a head in Figure 1, and from the rear, with a head, in Figure 3. Figure 1 shows the three major parts of the Exciter Body. The cylindrical magnet assembly is in the top center, the polished field supply and cooling system are below, and the pedestal is at the bottom and sides. The circle-X opening in the top center of the magnet structure accepts the moving element of the head, and the four holes at the top periphery accept the guidance pins. Sixteen openings in the upper iron cover admit cooling air to drive coil and to the field coils. The magnet structure is "double-ended", with field coils both above and below the air gap. The "double-ended" construction provides not only magnetic shielding for the test object, but also a very high magnetic flux density in the air gap, giving a large force generating capability with minimum amplifier power.

The field coils are excited by direct current, which is converted from the alternating current mains by a Field Supply. The field supply is built around the blower motor just below the blower scroll and acoustic muffler. A different sized field supply is required for each of the three Exciter Body sizes. This location of the field supply in the vibration exciter differs from the common practice of mounting the field supply in the amplifier cabinet. This location is preferable because of its greater convenience to the user,

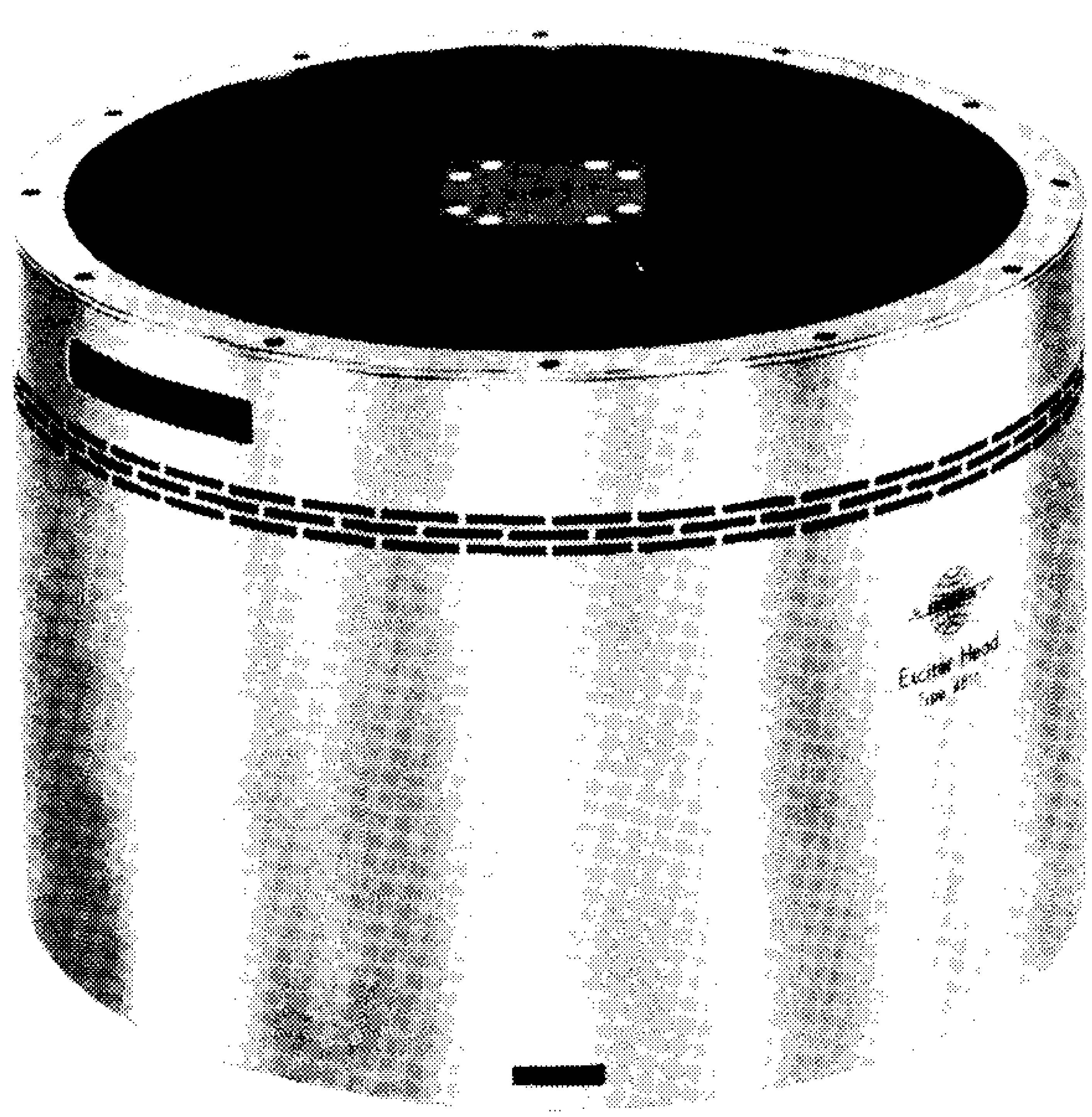


Figure 2. S Big Table Head

making it easy for him to use his vibration exciter with any of the amplifier sizes interchangably.

The Exciter Body and Exciter Head are provided with extensive protective features. One of the most important is over temperature protection, which protects both the Exciter Body and Exciter Head from damage due to a shortage of air flow. Another group of protective circuits associated with the accompanying amplifiers prevent excessive driver coil current, including a circuit which prevents application of driver coil power to a head which is not on the Exciter Body.

Airflow Acoustic Silencing
Air to cool the drive coil and field coils enters thorugh the perforated band at the top of the Exciter Head, passes through the magnet assembly, and exits at the rear through the rectangular opening shown just below the dark band in Figure 3.

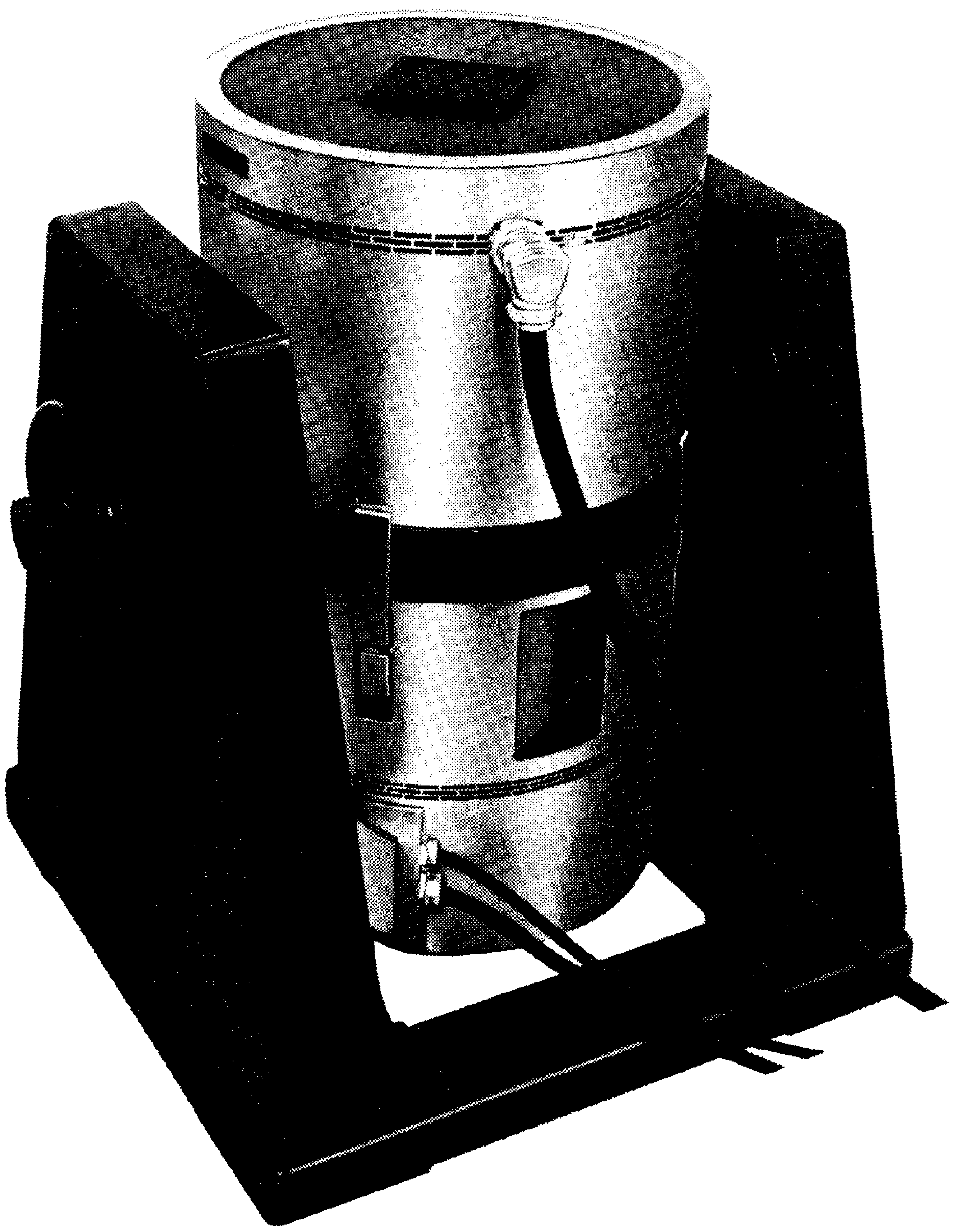


Figure 3. Rear View of S Exciter Body with S General Purpose Head

Blowers to provide the large volume of air at high pressure needed to cool a high performance vibration exciter tend to the both large and noisy. This acoustic noise is undesirable, not only because it is irritating to the user, but also because it obscures those tell-tale sounds from the tested object that indicate malfunction.

Heretofore it has been the practice either to put the large blower on the Vibration Exciter, and accept the high acoustic noise level, or to place the large blower in a remote location. If the blower is remote, the large diameter air hose between the vibration exciter and the blower is easy to trip over and makes positioning of the vibration exciter inflexible.

The solution chosen here is to use a smaller than normal blower, running at a higher than normal speed to obtain the required air volume and pressure, followed by an efficient dissipative muffler to reduce the acoustic output. The acoustic noise transmitted from the blower in the other direction, toward the air inlet, is attenuated by a number of acoustic mis-matches. The result is an acoustically self-contained, relatively quiet machine.

Pedestal and Body Suspension

The pedestal flexibly supports the vibration exciter and positions it at any desired angle through $\pm 180^{\circ}$. The larger of the two controls on each side of the vibration exciter is used to expand a brake wheel. When the two larger controls are loosened, the vibration exciter may be rotated to any desired angular position, and the controls lightened to expand the brake wheel and lock the vibration exciter in the new orientation.

When both of the smaller of the two side controls are tightened to their counter clockwise limit, the low frequency suspension springs are operable. When the smaller controls are tightened to their clockwise limit, a highly damped high frequency suspension is engaged. The resonant frequencies of these two body suspensions are in the 10 to 15 Hz and 30 to 50 Hz ranges respectively. Both suspensions are free along the vibration exciter axis, but stiff transverse to the axis, to simplify alignment with slip tables and push rods. The low frequency suspension is used whenever a high degree of isolation from the building is required. For most applications the high frequency suspension is engaged all of the time. The highly damped high frequency suspension is particularly useful for continuous spectrum, wide frequency range random and shock testing.

Exciter Head Construction

The external appearance of a typical exciter head, the S Big Table Head, is shown in Figure 2. The interior construction of the same head is shown in

Figure 4. Each of the heads is housed in a stainless steel can which protects the driver coil and guidance pins from damage. (In the M size, the lower end of the can is omitted to reduce the head weight and the strength of the guidance pins is increased to take over the protective function).

To mount a V or S head, one man picks up the head with his fingers in the openings shown just above the air inlet perforation band and slides the head down over the exciter body. The M heads are heavier and are installed either by two men with the exciter body in the horizontal position or by a hoist with the exciter body in the vertical position.

When an exciter head is placed on the exciter body, the latches on the exciter body engage into the openings at the lower edge of the can. The latch forces supplement the magnetic forces holding the exciter head to the exciter body, and, when the vibration exciter is aimed downward, keep the head on the exciter body when the field power is turned off.

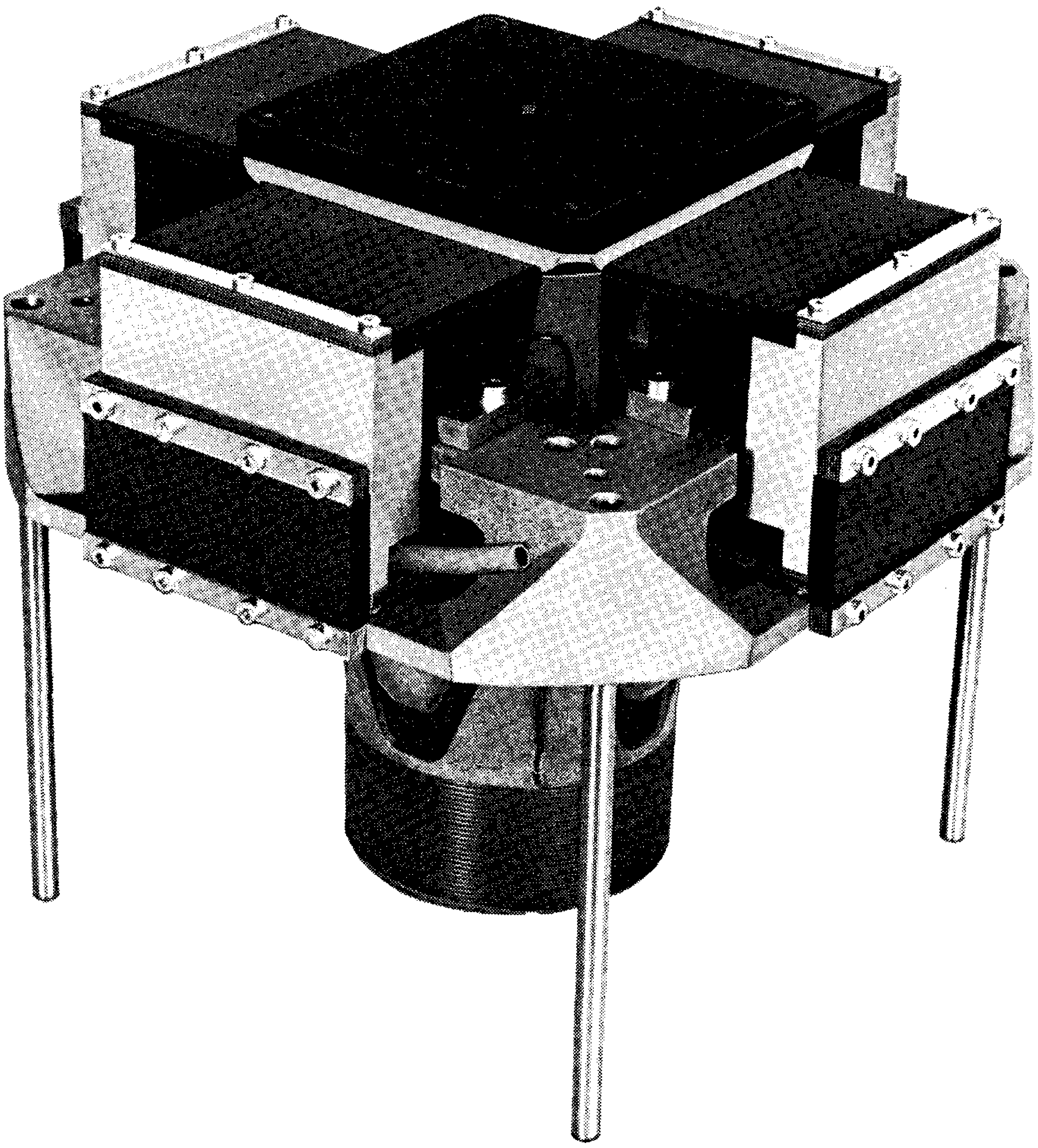


Figure 4. Inside View of S Big Table Head

At the top of each exciter head is a flexible black boot which prevents tools, mounting bolts, and other debris from falling into the vibration exciter. The underside of the rubber boot is reinforced with nylon in the highly stressed regions. Since it is desired that the active area of the boot be a minimum to reduce the acoustic output of the boot, the outer part of the boot is bonded to a slightly flexible, highly damped support structure.

A low stray magnetic field above the table is frequently important to prevent mis-operation of the test object. A combination of generous iron sections in the magnet structure and, when required, additional static shielding, reduces the flux density levels to a low value. In Figure 4, a magnetic shield is shown mounted just below the upper flexure.

Replacable Fuse Inserts
All of the exciter heads except the V Calibrator Head are provided with replaceable "fuse" inserts. Fuse inserts protect the moving element from abuse in a way analogous to the protection of wiring by electrical fuses. These inserts are available with either english or metric internal threads. The fusable feature minimizes the chance of damage to the exciter head by excessive mounting bolt loads.

As an example of the value of fusable inserts, the fusable inserts greatly reduce the chance of damage due to the use of over length bolts to attach a test object. As an over length bolt is tightened, it bottoms in the insert hole and pries upward on the internal threads of the insert. In a "fusable" insert, these internal threads fail before any other damage is caused. If a standard steel insert is used, the table is weaker than the insert, and typically a section of the table is pried out.

Mounting Surface
The mounting surface of each exciter head is hardened and lapped flat. The resulting surface is both resistant to abuse and capable of intimate coupling over the entire table surface to the test object.

Head Alignment
The alignment of each head with the Exciter Body is critical. Good manufacturing tooling is used to insure that the coil of every head is centered in the air gap. In a vibration exciter without the interchangable head feature, the coil may be shimmed to center it in the air gap and the guidance system tightened to hold it in position. For interchangable head vibration exciters the requirements are much more severe: The tolerances on each exciter body and on each exciter head are closely held to insure that every exciter head fits every exciter body.

The pins shown extending downward from the corners of the frame in Figure 4 guide the head onto the body. In some heads the iron tongues, which complete the upper magnetic circuit when the head is installed, provide additional guidance. In Figure 4 the tip of one of these tongues is shown extending downward toward the coil in the lower left center of the picture.

Driver Coils

The driver coils are fabricated from two layers of wire, wound inside and outside of a blade extension of the moving element. Some of the coils are made of aluminium wire and some of copper wire. Aluminium wire has a lower density than copper wire and is used whenever weight is of major importance, for the High G, Mode Study, and Calibrator Heads. Copper wire has a lower resistivity than aluminium wire, permitting higher currents for the same temperature rise, and is used whenever maximum force is more important than light weight, for the General Purpose and Big Table Heads. All of the coils are wound of rectangular wire, with a very thin high temperature insulation to improve the space factor and minimize the generated heat.

Standardized Table Patterns

A standardized sequence of table insert patterns is used on the heads of the V, S, and M vibration exciters. This is particularly important to the user having exciters of more than one size in his laboratory since it greatly simplifies fixturing.

The ratio of one size to the next is approximately 1 to 1.5. The diameters, in inches, of the outer bolt circles of the High G, General Purpose, and Big Table Heads are 2, 3, and 4.5 for the V; 3, 4.5, and 6.75 for the S; and 4.5, 6.75, and 10 for the M.

As an example, consider the development of a new device that might be mounted on a fixture with a 4.5 inch outer bolt circle. In the early development stages, low acceleration level testing on the V Big Table Head might be used. When most of the problems have been worked out of the device, the same fixture can be mounted on the S General Purpose Head for higher acceleration level testing. Finally, if operation in very severe environments is necessary, the same fixture can be mounted on the M High G head and driven to very high acceleration levels.

Moving Element Suspension

The suspension system of each exciter head is designed to favor the performance desired of that head. The various designs strike different balances between high strength, low weight, length of stroke, and minimum cross motion. High Strength, the capability to withstand large moments applied to the table and to support large overhung loads for horizontal testing, is a major factor in the suspension design for the Big Table Head and is progressively less important for the General Purpose and High G Heads. Since the flexure system contributes to the moving element weight, low suspension system weight is particularly critical for the High G and Mode Study Heads. Long stroke is essential for the Mode Study Head but less significant for the other heads. Low cross motion is important for all heads, and becomes a major criteria of the design of the Calibrator Head.

The moving element suspension systems of all heads provide support for the test object and guide the moving element so that the coil does not rub in the air gap. All of the suspension systems are strong enough to support the weight of typical test objects for horizontal testing. A not-so-obvious requirement of all heads is that all resonances of the suspension system must be highly damped to avoid undesired motions of the moving element, distortion magnification, and undesirable irregularities in the current or voltage transfer functions that might affect structural measurements or equalization for random or shock testing.

Although the suspension systems of the V, S, and M heads differ in detail from head to head, all have eight radial flexures, four outer flexures, and four floating blocks. Referring to Figure 4, the inner ends of the radial flexures are attached to the moving element skeleton and the outer ends to the four floating blocks. The floating blocks are supported from the frame by the four flexures. When the moving element moves either up or down from the neutral position the outer flexures allow the floating blocks to move inward to accommodate the reduction in length of the radial flexures as they bend.

Each individual flexure is a multi-layer sandwich of spring steel leaves and layers of a highly damped elastomer. The magnification factors, or Q's, of the resonances of these flexures are typically 1.5 to 2. Each flexure bends easily in the thin direction but resists transverse deformation.

When large horizontal loads are to be supported, the major design parameter is the shear stiffness and side bending stiffness of the metal leaves in the flexures. Only slightly less critical parameters are the buckling of the individual flexure sandwiches, torsion of the outer blocks, deformation of the moving element, and deformation of the frame.

Resonances in suspension systems have always been troublesome and many types of suspension systems have been tried. Many years ago it was common to add slidable weights to flexures to detune the flexure resonance from the frequency of operation, but this is impractical whenever wide frequency range operation is needed. Many geometrical forms of ball and roller bearings have been tried as guides, but have not been too successful because the combination of large local stresses with vibration magnifies the problems of wear, galling, and cold welding. Oil film bearings, particularly of the hydrostatic type, look very attractive at first; however to prevent binding of bearings due to thermal expansion of the moving element, the bearings must be on the axis of the moving element and the location of the main side-load carrying bearing is under the center of the table, just where skeletal structure is most needed.

Resonances exist in all types of suspension systems, and if bad performance is to be avoided at these resonances, each resonance must be effectively damped. All successful modern vibration exciters have well damped suspensions. This damping has the desirable effect of improving performance, but the undesirable effect of generating heat. A common cause of suspension system failure in modern vibration exciters is the burning up of the damping producing members of the suspension whenever the vibration exciter is operated continuously at the suspension resonances.

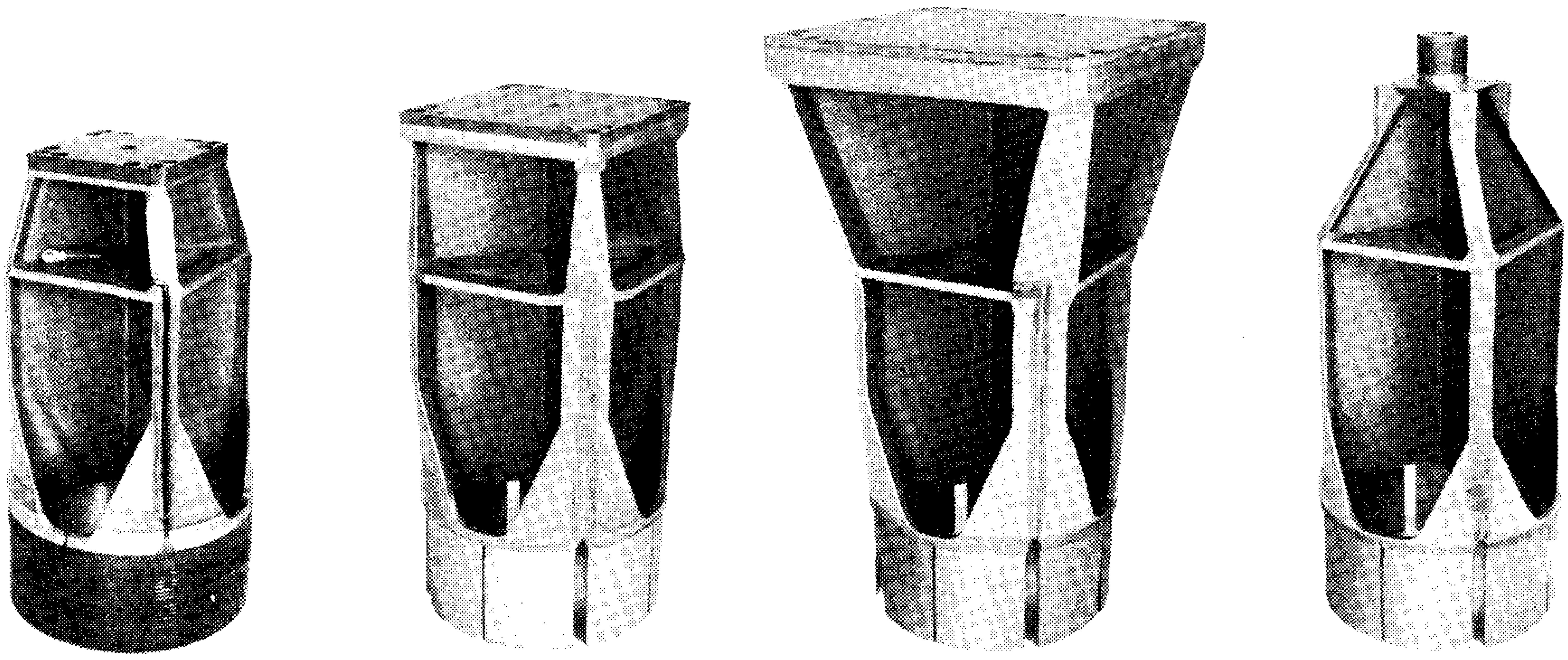
The suspension overheating problem is minimized in these heads by providing a large surface area to volume ratio for each of the flexures and a continuous air flow over these surfaces to remove the generated heat.

Skeletons

The geometry of the various moving element skeletons illustrates how the designs of the exciter heads are adjusted to maximize different performance criteria. The skeleton is the structural part of the moving element. The skeletons of five different heads, two with driver coils, are shown in Figures 5 and 6.

The high performance required of each of the heads requires very tight tolerances and close control of skeleton mass and stiffness. In addition, the light weight skeletons require thin, uniform main ribs and very thin auxiliary ribs. Conventional casting, machining, and welding techniques are incapable of achieving these requirements and more sophisticated techniques are necessary.

To achieve the tolerances required of the V and S skeletons the electrical discharge machining (EDM) process is used. With precision fixturing and frequent re-dressing of the electrodes, tolerances of a very few thousands of an inch (less than 0.1 mm) are routinely achieved.



5a High G *5b General Purpose* *5c Big Table* *5d Mode Study*

Figure 5. Skeletons of the Four S Exciter Heads

The M skeletons are fabricated by a precision investment casting technique. Careful control and special tools are used to accurately form the thin rib wax replicas and to maintain the dimensions of the finished high strength aluminium alloy skeletons.

Each moving element has a high strength aluminium alloy skeleton that attaches all of the parts of the moving element together. The skeleton is designed to provide the best possible coupling of the force generated by the driver coil at one end to the test object on the table at the other end, within the limitation set by the allowable weight of the moving element.

The driver coil has two layers, one inside and one outside of a blade-like extension of the lower end of the skeleton. One side of every driver coil turn is bonded directly to the blade with a high strength, high temperature, structural adhesive. Since the blade is an integral part of the skeleton a very stiff, high strength attachment of the coil to the skeleton is achieved.

The force collected by the blade from the driver coil passes upward through four triangular shaped load distributing gussets into the four ribs of the skeleton and into the four rib-edge beams. The ribs and rib edge beams pass the force upwards to the table.

In the High G, General Purpose, and Big Table skeletons, shown in Figures 5a, 5b, and 5c, the center insert of the table is in an enlarged upward continuation of the intersection of the ribs. In these same moving elements, the outer four inserts are in enlarged upward continuations of the rib-edge beams. The design is such that approximately equal stiffness exists between the driver coil and each of the inserts so that deformation, or "diaphramming", of the table top surface is small, thus minimizing any damage to the test object that might be caused by base bending. Deep auxiliary ribs under the table and a heavy skirt at the outer edge of the table provide stiffness to the entire upper surface of the table, so that a stiff coupling to the test object can be achieved.

For the Mode Study moving element, shown in Figure 5d, the connection to the test object is from the force takeoff insert in the top center of the moving element. All of the force both from the ribs and from the rib-edge beams, is collected to this one location.

The V Calibrator skeleton is shown in Figure 6. In a high acceleration, high frequency confirmation calibrator, the weight must be kept to a minimum to achieve continuous operation at 100 g with substantial payloads, yet the structure must be stiff to achieve an axial resonance of the system above the operating frequency range. The gussets, ribs and rib-edge beams are proportionally thicker than in the other skeletons to achieve the high frequency

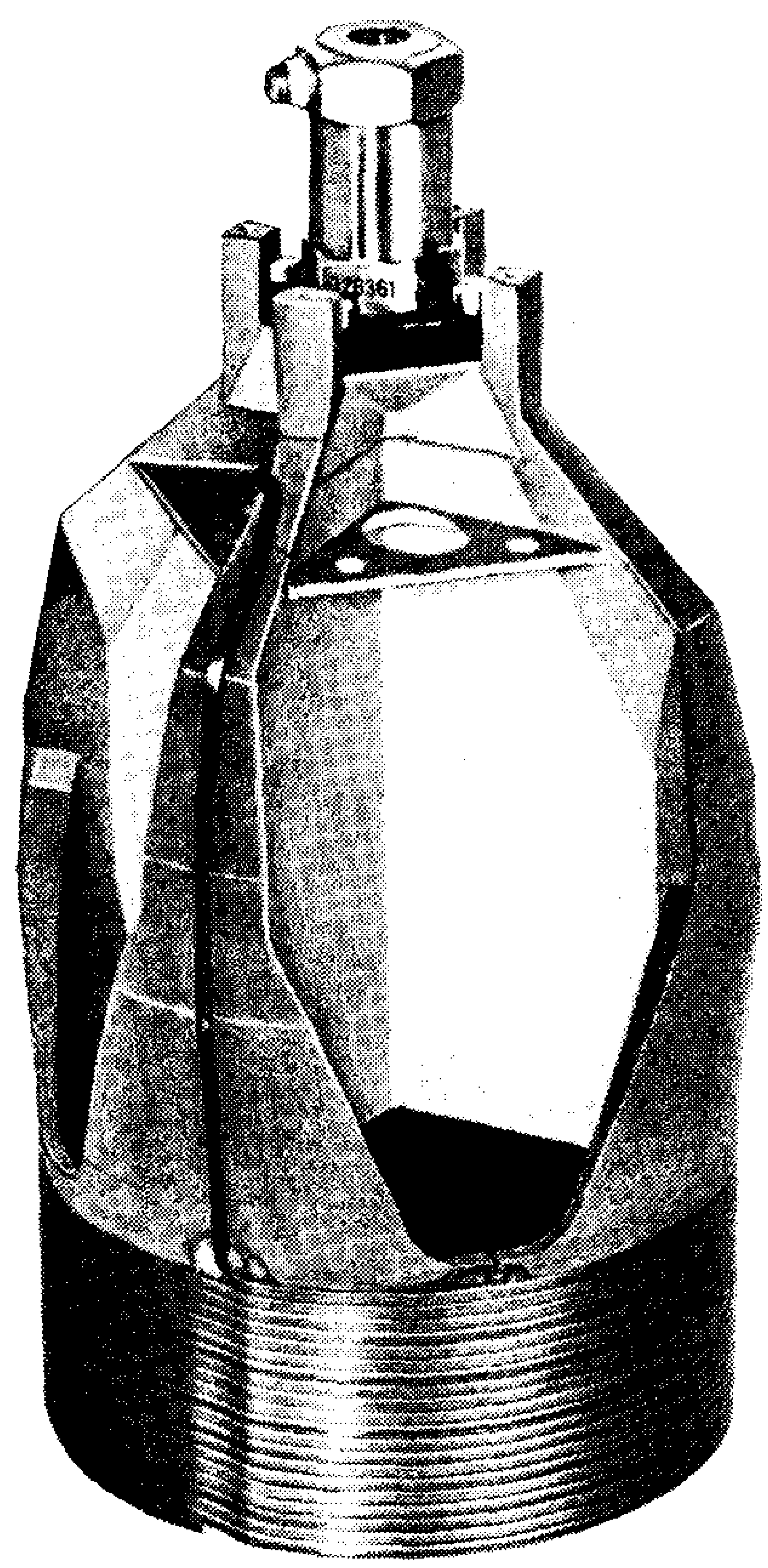


Figure 6. Skeleton of the V Calibrator Head

operation. A solid cylindrical block of stainless steel, part of the reference accelerometer, forms the table. The measurement quartz crystal and mass are mounted to the underside of this table. A short, heavy walled, stainless steel tube connects the table to a flanged base. The skeleton incorporates an inverted pyramid under this flanged base and direct connections from the rib-edge beams to the flange to distribute all of the force from the skeleton into the stainless steel tube. The result is a stiff structure connecting the driver coil to the table.

The skeletons of the High G, General Purpose, and Big Table Heads are shown in Figures 5a, 5b, and 5c. These three heads are primarily used to vibrate test objects mounted on the table surfaces. The useful range of operation varies from one extreme, the testing of large objects at low acceleration levels, to the other extreme, the testing of small objects at very high acceleration levels. The skeletons of these three heads are optimized for different portions of this range.

The skeleton of the High G Head, shown in Figure 5a, is light in weight, yet has a high resonant frequency, a stiff table, and a table insert pattern of more than adequate size for high acceleration test objects. The achievement of the low moving element weight needed for "over 200 g" operation, while maintaining the close distribution of stiffness and mass needed for low cross motion, requires not only thin rib and gusset cross sections but very close control of the tolerances as well. The EDM and precision investment casting techniques are effectively used to create the High G skeleton.

The skeleton of the Big Table Head, shown in Figure 5c, is at the other extreme of the range from the High G skeleton. Since weight is not nearly so critical on the Big Table skeleton, a much stiffer structure is used. The table is unusually large, to simplify the mounting of big test objects. The ribs and rib-edge beams are generous in cross section to provide a very stiff structure between the driver coil and each of the inserts. The very stiff structure is particularly effective in the prevention of table deformation over the operating frequency range and in the maintenance of a high moving element first resonance frequency, even with heavy loads.

The skeleton of the General Purpose Head is shown in Figure 5b. A great amount of effort has been given to the design of this skeleton, so that, even with a relatively large table and high force copper coil, both high payloads at high accelerations and high first resonance frequency are achieved. The distribution of weight and stiffness is particularly critical on this skeleton and have been carefully designed and controlled to produce the desired result.

Summary

Vibration Exciters with Interchangeable Heads provide a new tool for improved vibration generation and measurement. By choosing the head best adapted to the job to be done, the user is more confident that his vibration environment tests will be realistic, and that his transducer calibrations and his structural measurements will be accurate.

AEROS: A Generalized-Spectrum Vibration-Control System*)

by

Theron Usher, Jr., D.Eng. **)

ABSTRACT

Vibration test engineers have heretofore been faced with buying separate equipment for controlling random and shock tests. As a solution to this problem, a fully Automatic Equalizer, for Random or Shock (AEROS) vibration testing is described. Novel features of the system include narrow-band equalization for either random or shock signals, simplified display techniques, and self-calibrating procedures. The system may also be used as a spectral analyzer. A wide variety of options are available to cover the signal band between 1 Hz and 10 kHz, in order to satisfy a wide variety of testing needs.

SOMMAIRE

Les ingénieurs en vibration sont souvent amenés à envisager l'acquisition d'un équipement particulier pour les essais aléatoires et les essais aux chocs. L'ensemble analyseur-égalisateur entièrement automatique que nous décrivons ici est destiné à répondre à ce besoin. Les caractéristiques originales de ce système sont: l'égalisation en bande étroite pour tous les signaux aléatoires aux chocs, un procédé de visualisation simple et enfin des possibilités d'auto-étalonnage. Cet ensemble peut aussi être employé comme analyseur de spectre. Il est prévu toute une gamme d'options qui permettent de couvrir une bande de fréquence entre 1 Hz et 10 kHz dans le but de répondre à la plupart des besoins.

ZUSAMMENFASSUNG

In der Vibrations-Prüftechnik waren die Ingenieure bisher gezwungen, separate Apparaturen für die Steuerung von Rauschprüfungen und für Schockspektrum-Tests zu beschaffen. Als mögliche Lösung für dieses Problem wird ein vollautomatischer Spektrumentzerrer für Rauschprüfungen und auch Schockspektrum-Tests beschrieben. Neuartige Eigenschaften des Systems sind die schmalbandige Spektrumentzerrung für sowohl Breitbandrauschen als auch Schockspektrum-Test, seine vereinfachte Anzeigetechnik und die Einrichtung zur selbständigen Kalibrierung. Das System kann auch als Frequenzanalysator verwendet werden. Eine Vielzahl von möglichen Ergänzungen ist verfügbar, um den gesamten Frequenzbereich von 1 Hz bis 10 kHz abzudecken, damit alle nur denkbaren Prüfaufgaben bewältigt werden können.

Introduction

AEROS is an acronym for Automatic Equalizer, Random or Shock. More completely, AEROS is a fully automatic equalizer-analyzer system for either shock or random vibration testing. One set of equalizer filters, one set of analyzer filters and the associated electronics is used for both types of

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*) Paper presented at the 17th Annual IES Technical Meeting, Los Angeles, 26-30 April 1971.

**) Booth, Brüel & Kjær, Inc., Branford, Connecticut.

testing. The engineer no longer has to acquire a separate system for each use. Before further discussion of AEROS, and for a better understanding of its development, a brief review of random and shock vibration testing equipment follows.

Parallel-filter equalizer-analyzer systems for providing automatic synthesis of vibration test spectra for random signals have been in use for about a decade.[1,2] More recently, parallel-filter shock synthesis systems have been introduced for providing oscillatory acceleration shock pulses for vibration testing.[3,4] Other parallel-filter systems have been used for shock spectrum analysis.[5]

All of these systems have met definite testing needs but a number of deficiencies have been found, and new testing needs have developed. AEROS has been designed to overcome the deficiencies and meet the newer testing needs.

Random vibration spectral equalizers now in use have a maximum total bandwidth of 2 to 4 kHz, and a low-frequency limit of 10 to 20 Hz. The individual filter bandwidths below 1000 Hz also have been somewhat large for equalizing complex test specimens.

The earlier shock synthesis systems generally require manual gain adjustment of the filter channels, and the filter channels are usually far too wide (approximately 1/3 octave or 23%) to provide adequate equalization for narrow-band specimen resonances. The equalization requirements for providing a required shock spectrum for a given shaker-specimen combination are just as severe as the corresponding requirements for random vibration testing.

The shock spectrum measurement technique is often complicated by the provision of electronic analogs to satisfy the original empirical definitions of shock spectra.[6] The complication is enhanced by the fact that the original definitions were generated in part by the use of shock pulse equipment which produced pulses of given shapes, such as half-sine, terminal-peak sawtooth, etc. Parallel-filter spectrum synthesizers produce oscillatory signals having no simply specified waveshape or time-history, and thus some of the empirically-generated definitions for shock spectra have little or limited meaning. This point will be discussed in more depth in a later section.

As a consequence of the previous commentary, the design goals for AEROS, which are discussed in the following section, may be better understood.

Design Goals

It has been established that AEROS is designed to provide fully automatic spectral equalization for either random or shock vibration testing. Cost and equipment economics are obtained by the use of the same sets of filters for both types of testing.

For random operation, AEROS provides equalization at the full test level, or, if preferred, at 20 dB below the test level. For the latter situation, the low-level equalization period is followed by a burst at the full test level. Automatic timing for the test interval is also provided.

For shock operation, automatic equalization is provided at 20 dB below the full test level with repetitive shocks. Following equalization, the operator may apply one or more shocks at the specified test level.

The maximum frequency range from 1 to 10,000 Hz may be covered by filter sets of 120, 180, or 240 filters. The extension of the low frequency end below the 10 to 20 Hz limit of previously existing equipment provides capability for low-frequency testing for large vehicle and shipboard equipment and also for seismic shock simulation. The extension of the previously existing upper limits to 10,000 Hz allows single-run wide-band tests rather than tests conducted in successive 2 kHz segments.

The use of active filter design allows sufficient component duplication so that great flexibility is possible in selecting the desired filter system for each portion of the 1-10,000 Hz range. The pertinent specifications for these filter systems are summarized in Table 1.

System	Range (Hz)	No. of Channels	Filter Bandwidths (Hz)
A	20–2000	30	20 to 100
B	20–2000	60	10 to 50
C	20–2000	120	5 to 25
D	20–2000	150	2.5 to 10
E	1–20	10	1 to 2.8
F	2K–10K	100	30 to 175
G	2K–10K	50	60 to 350

Table 1. Filter System Summary

A photograph of AEROS containing filter system C is shown in Figure 1.

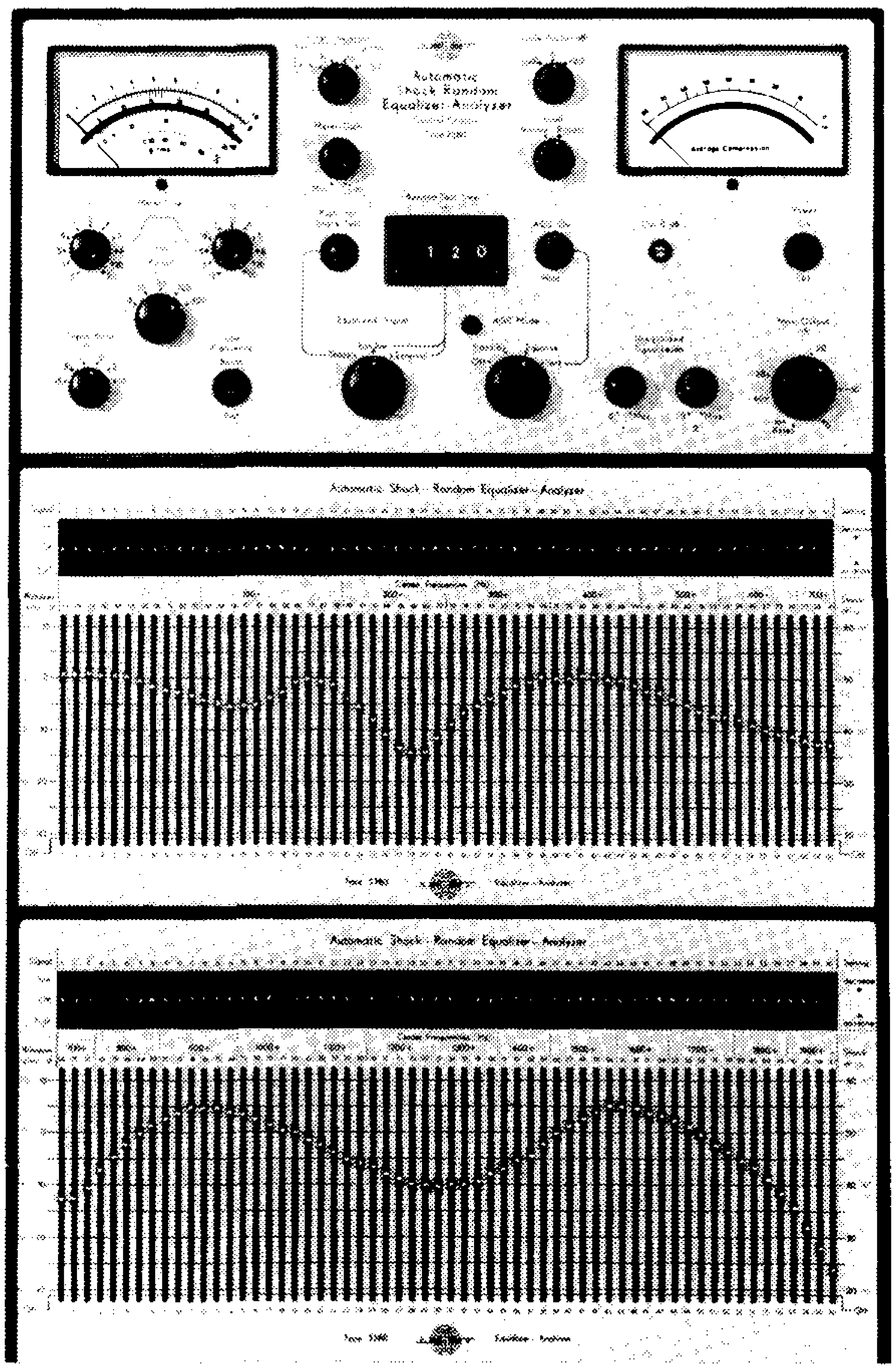


Figure 1. AEROS, Filter System C

The two lower or Equalizer/Analyzer chassis each house 60 complete filter channels, including the control used to set the spectrum level in that channel. A complete 240 channel system can be housed in a maximum of five chassis, requiring only 43.75" of standard rack panel space.

The flexibility of filter choice within each system is demonstrated by the fact that one filter in systems A through C may be replaced directly by two filters from the system with the next following letter. For example, one "B" filter may be replaced ty two "C" filters. This allows narrow bandwidth filters in difficult-to-equalize portions of the spectrum.

The filter bandwidths in Table 1 vary gradually from the lower value to the upper value as center frequency increases. Inspection reveals that systems A through E are neither constant bandwidth nor constant percentage bandwidth. One design goal for random operation is narrower bandwidths at lower frequencies. However, a constant percentage bandwidth system for a 2000 : 1 frequency range would cause an unwieldly number of filters and extremely long analysis time if reasonably narrow bandwidth were maintained at 2 kHz.

A requirement for shock operation is the production of an oscillatory pulse, which is obtained by frequency-dispersive spreading of a step input to the equalizer filters. Other systems have accomplished this with constant percentage bandwidth filters. All that is actually necessary is a significant bandwidth change from the low end of the frequency range to the high end, which is accomplished by the 1 : 4 change in bandwidth in Table 1 for systems A through C.

Thus for a system designed for both shock and random signal operation, the equalizer filters cannot have constant bandwidth, which is prohibited by shock operation, nor can they have constant percentage bandwidth which is prohibited by the design goals of reasonably narrow bandwidths and a reasonable number of filters for the frequency range. Systems F and G have constant percentage bandwidth filters; but the frequency range is small enough (5 : 1) so that the number of filters is not too large.

The spectral test levels are set on the front of each filter chassis by means of linear sliders. The range is 40 dB in 1 dB steps. A scale multiplier on the control chassis allows test levels from 10^{-4} to 100 g^2/Hz for random testing and spectra from 3 to 10,000 g. for shock testing. The upper and lower limits are, of course, modified by the capabilities of the amplifier and shaker used in the complete testing system.

The operation of AEROS is described in detail in the following section. Other applications and important features are pointed out.

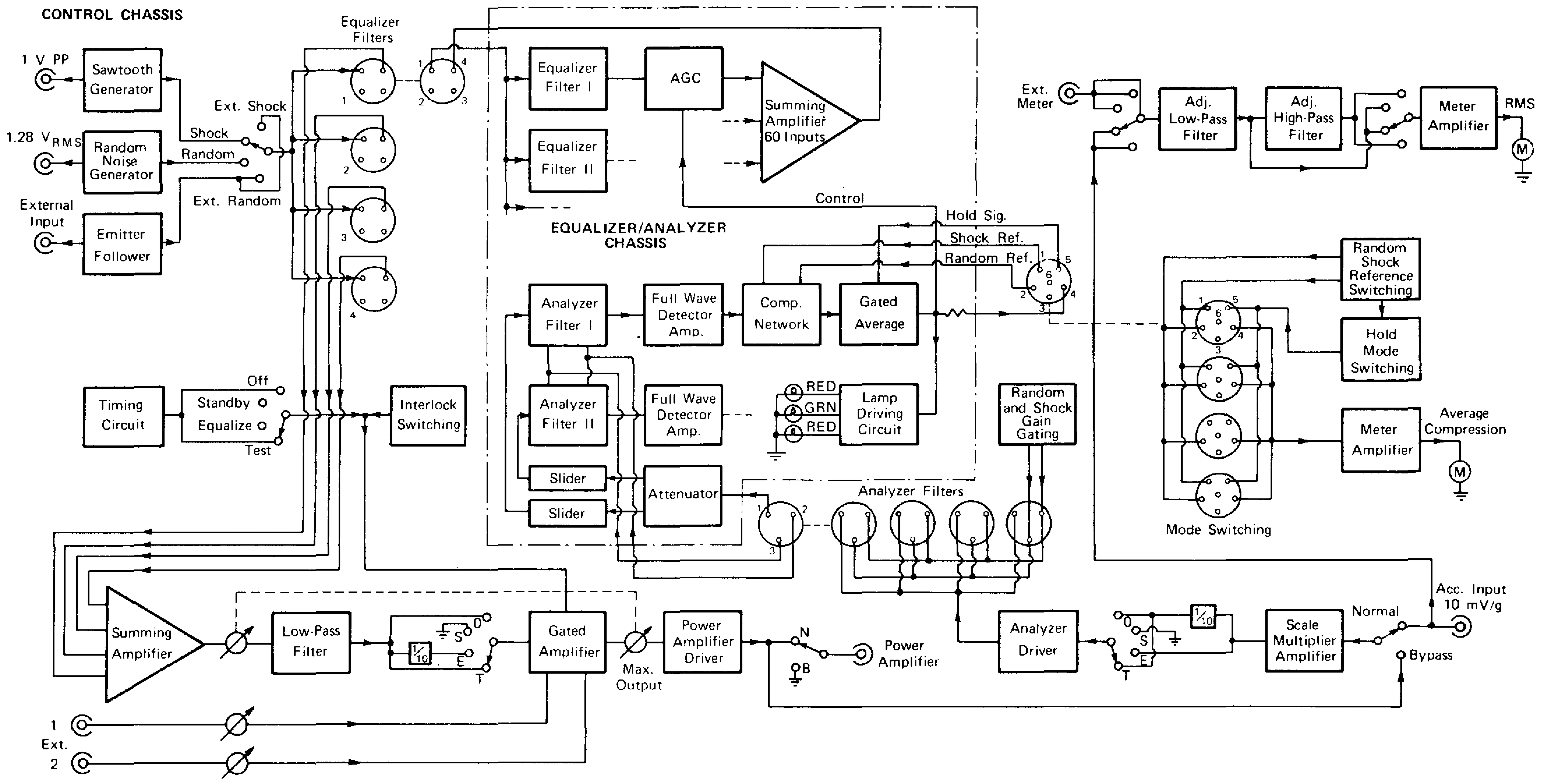


Figure 2. AEROS Block Diagram

Operation
The block diagram in Figure 2 will assist in the description of system operation. Only one channel in the Equalizer/Analyzer chassis is shown for simplicity.

Either of the two calibrated internal signal sources or an external source is switch-selected and fed to the parallel-connected equalizer filters. After passing through the AGC circuits, all signals are summed, filtered, and fed to the power amplifier. Any switching of controls in the control loop during a test causes the gated amplifier to remove the signal to the power amplifier.

The acceleration signal from the control point is fed through the level-changing circuits and drives the parallel-connected attenuators. Each attenuator serves two channels, the two slider switches feeding the corresponding gain-gated analyzer filters, detectors, comparators, and gated averaging circuits. The acceleration signal may be obtained from a multiplexer type of averager.

The output of each gated averaging circuit is used to control the gain of the corresponding AGC circuit. The output of each averaging circuit also drives a three-lamp display circuit. Physically, these lamps are located directly above the corresponding level-setting control in Figure 1. All averaging circuits simultaneously drive a meter which indicates the average compression of all AGC circuits.

Selection of the desired signal excitation also automatically provides the correct reference voltages for the comparator circuits. The outputs of all averaging circuits may be held constant by means of a front panel HOLD control. This allows the equalization to be fixed at any time. The HOLD feature permits pre-equalization of the testing system for use with an arbitrary external signal. Such a signal could be directly recorded from the environment and contain not only shocks and a random component, but also periodic components.

The HOLD feature allows system frequency responses to be made following equalization, thus giving a record of the output spectral density. The acceleration spectral density is given by

$$S_g(\omega) = |H(j\omega)|^2 S_i(\omega) \qquad (1)$$

The spectral density of the internal random source $S_i(\omega)$ is flat so that the plot of frequency response $|H(j\omega)|$ on log-coordinates gives the acceleration spectral density. For shock inputs the acceleration shock spectrum $G(\omega)$ is given by

$$G(\omega) = |H(j\omega)||\omega F_i(\omega)| \quad (2)$$

where $F_i(\omega)$ is the Fourier Transform of a single input pulse. The product $|\omega F_i(\omega)|$ is flat over the frequency range of interest of the internal source, so that a logarithmic plot of $|H(j\omega)|$ yields the shock spectrum.

AEROS may also be used directly as a spectral analyzer. A constant or reference level for acceleration spectral density or shock spectrum is set on all level-setting controls. The external signal is fed to the system. A bypass control allows the power amplifier output to be fed directly to the acceleration input, thus bypassing the amplifier and shaker. AEROS is then allowed to equalize the output signal to yield the required flat spectral density or shock spectrum. The HOLD mode is actuated and a frequency response is recorded. From Eq. (1), and Eq. (2) we have

$$S_i(\omega) = S_g(\omega)/|H(j\omega)|^2 \quad (3)$$

$$|\omega F_i(\omega)| = G(\omega)/|H(j\omega)| \quad (4)$$

Since both $S_g(\omega)$ and $G(\omega)$ are flat in this situation, then $S_i(\omega)$ and $|\omega F_i(\omega)|$ are related to the inverse of $|H(\omega)|$. If $|H(j\omega)|$ is plotted on log coordinates, the required spectral information is obtained by labeling the scales in reverse order.

For the analysis of shock signals, the signal to be analyzed must be repetitive. This may be obtained by recording the acceleration during the equalization period of a test with AEROS, or by making a tape loop of a single pulse. The quantity $|\omega F_i(\omega)|$ is shown to be equivalent to shock spectrum in a later section.

Another important feature is that the design of the AGC loop provides zero static error between the desired spectrum value (level-setting indication) and the actual value. This is true over the entire range ($>$60 dB) of the AGC circuit. In other words, gain variations of 60 dB may be compressed to 0 dB static error!

The three-lamp display deserves further comment. The status of each channel is shown by the lighted lamp. The upper (red) lamp indicates maximum AGC gain, and too low a signal from the analyzer. The lower (red) lamp indicates minimum AGC gain and excessive signal amplitude. The middle (green) lamp indicates operation within normal AGC limits. The simplified lamp display is possible because of the zero-static-error AGC circuits. If the analyzer signal magnitude is not exactly the correct value, a correction signal is returned to the AGC circuit until either a balance is achieved (green light) or the maximum/minimum limit of the AGC circuit is reached (upper/lower red light). Thus if all green lights remain on, we conclude that equalization is complete. The meter displaying average compression stops moving in either direction when the dynamic equalization process is complete.

The provision for bypassing the amplifier/shaker also allows self-checking and calibration procedures to be easily accomplished.

An acceleration meter with low-pass and band-pass filtering is also included.

Shock Synthesis and Testing

The discussion initiated in the Introduction relative to shock spectrum measurement will be expanded in this section.

Shock testing philosophy has until recently concentrated heavily on the production of shock pulses having precisely defined waveshapes, such as half-sine, terminal-peak sawtooth, etc. The mathematical description of these shock pulses was also rather empirically developed and resulted in the definition of different types of shock spectra: initial, residual, positive, and negative.

However, in many cases the environment does not exhibit waveforms having limited time duration (shocks) which also have simply-described waveshapes. These observed shock waveforms are generally oscillatory in character and also have their Fourier spectra distributed over a reasonably wide range of frequencies. Quite possibly these observed shocks are the result of simpler shock waveforms having undergone time-spreading and general spectral filtering by being transmitted through complex non-minimum phase structures and/or dispersive media.

Electronic parallel-filter shock synthesizers, such as AEROS, have concentrated on simulating the oscillatory type of shock found commonly in the environment. This is generally accomplished by applying a pulse or pulses of a given waveshape to the parallel-filter bank which provides time-spreading for the frequency components and adjusts the spectral content according to the test specification.

It is well known, however, that an infinite number of oscillatory shock pulses with different time-histories can have identical Fourier spectra. The

Fourier spectrum is the magnitude of the Fourier transform, with the phase information discarded. The phase information is neglected for oscillatory shock testing because the phase information would be reasonably difficult to obtain from the environment samples and all but impossible to simulate.

Simple shock waveshapes, such as the half-sine, have Fourier spectra with precisely defined phase characteristics. A little reflection tells us that the four different types of *shock* spectra are dependent upon the waveshape of the shock pulse and therefore dependent upon the precisely defined phase characteristic of the Fourier transform. This connection, of course, is reasonably complicated mathematically.

For oscillatory shock testing, since we are not specifically concerned with reproducing wave shapes, four *different* definitions of shock spectrum become meaningless. It thus becomes convenient to adopt the simple relationship between the residual shock spectrum for zero damping and the Fourier spectrum for situations in which phase is not important. From Reference 8 we have

$$A_g(\omega) = \omega |F_g(\omega)| \tag{5}$$

where $A_g(\omega)$ – shock spectrum in g's
$F_g(\omega)$ – Fourier transform in g-sec
ω – rad/sec.

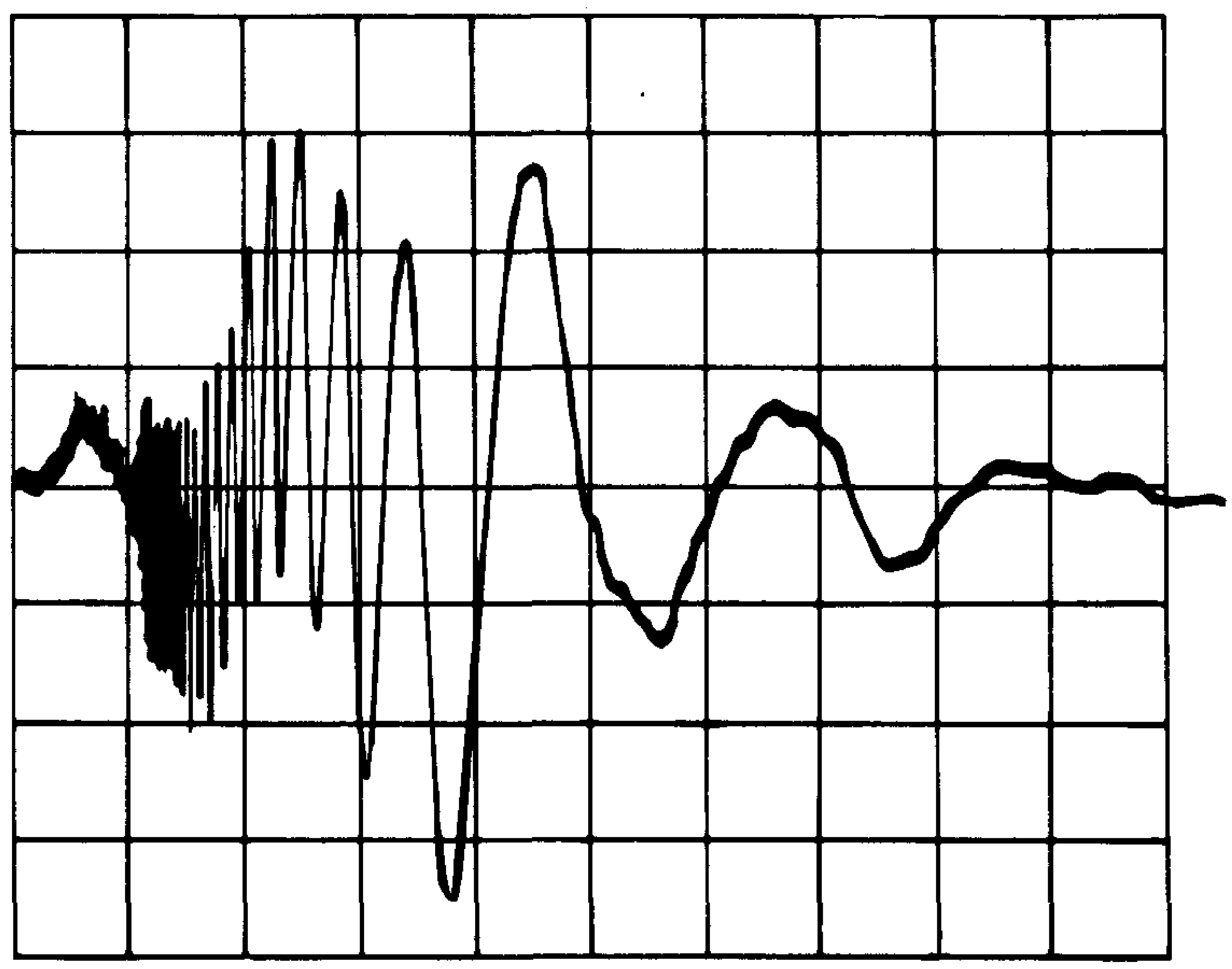
With the relationship in Eq. (5), the measurement technique for shock spectrum does not need to be dependent upon peak-holding analogs of second-order systems. Other techniques for estimating $|F_g(\omega)|$, such as that used in AEROS, are equally valid.

An example of a time-spread oscillatory pulse is shown in Figure 3. A 10 V terminal-peak sawtooth was applied to the filter system C in Table 1. The bank of filters was adjusted for a flat-unity gain response in the 20-2000 Hz pass-bands.

The results show a time delay of 20 msec before much response occurs, and then a fast swept-frequency output starting with the high frequencies first. The response magnitude decreases rapidly after 100 msec.

An advantage that accrues as a result of time-spreading is that the amplifier/shaker system does not have to handle the full acceleration range of the shock spectrum value. If the voltages were to represent accelerations in Figure 1, the shock spectrum of the input and output is flat over the

(a)



(b)

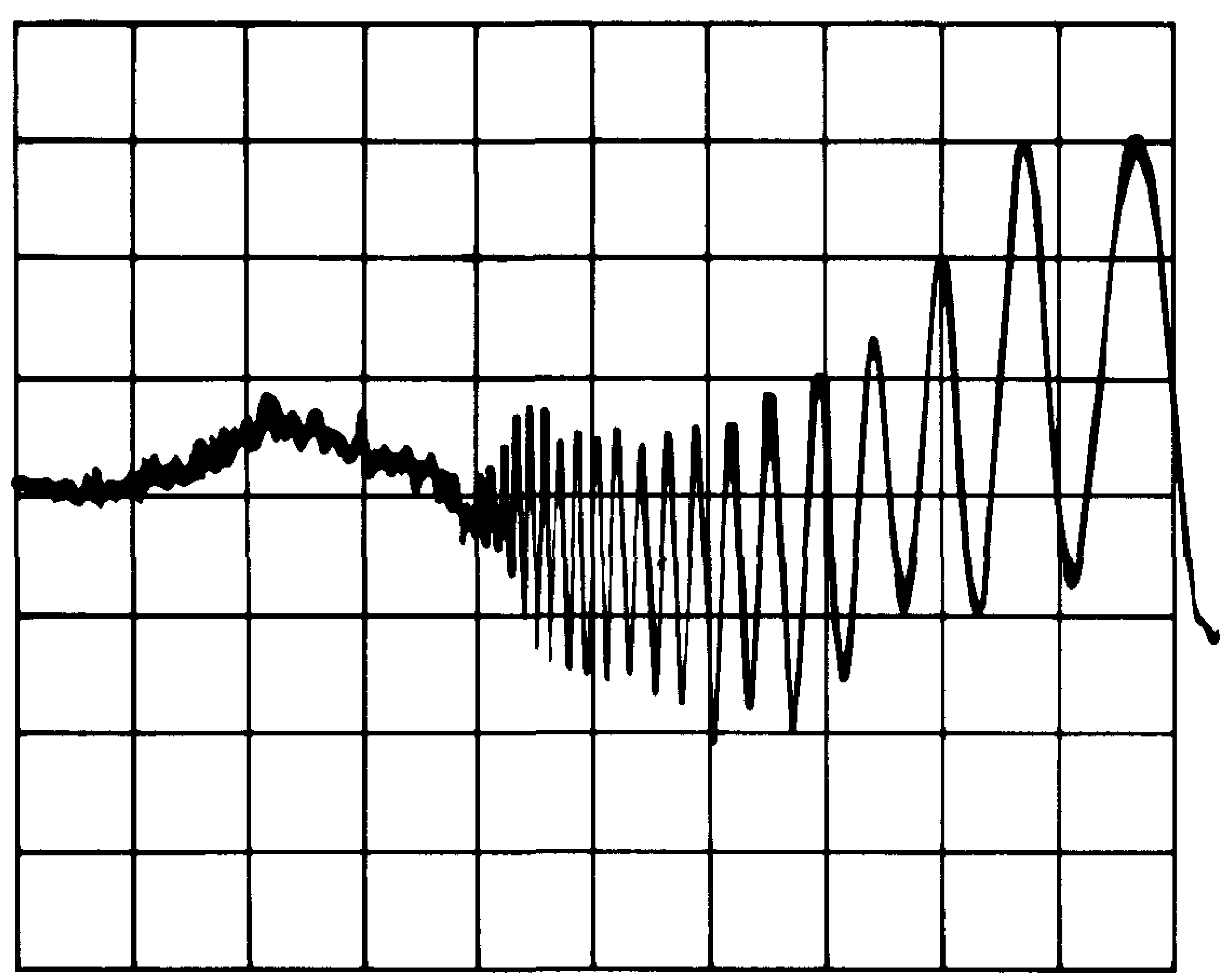


Figure 3. Oscillatory Shock Simulation, vertical 1 V/cm or 100 g/cm

(a) horizontal 20 msec/cm
(b) horizontal 5 msec/cm

frequency range at 1000 g. However, the output shows peak accelerations near 2000 Hz of only about 100 g and near 20 Hz of approximately 300 g. In an actual testing situation flat spectra would probably not be required to 20 Hz or lower, and the acceleration peaks would not be as high as those shown.

Filter Selection

The general applications of AEROS as a fully automatic equalizer for vibration testing, a pre-equalizer for testing with arbitrary input signals, and a spectrum analyzer have already been mentioned and discussed. Further comments concerning the applications of the filter systems in Table 1 follow. Combinations of the systems are possible because of the filter substitution possibilities noted earlier.

Groups of small components being tested simultaneously with the help of a single fixture generally do not cause peak-notch pairs in the shaker response that exceed the specification limits. System A has relatively large bandwidths and only 30 filters to provide the spectral shaping function to equalize the overall shaker response function for this application.

Specimens with non-critical equalization requirements can probably be handled with system B, (60 filters). System C (120 filters) is used for general-purpose testing situations with reasonably difficult equalization requirements. Filters in system D can be used as replacements for C filters for regions in which specimen resonances cause particularly difficult equalization problems. The D filters are also used with system E to satisfy narrow-bandwidth low-frequency testing requirements.

APPLICATION AREA	FREQ. RANGE (Hz)	FILTERS USED	TOTAL NO. FILTERS
Structures (Scale Model Testing)	1–2000	10E, 100C, 10B	120
	1–2000	10E, 100D, 70C	180
Low Freq. Testing Shipboard, Airplane, Vehicular Equipment	1–200	10E, 50D	60
	1–500	10E, 50C	60
	1–600	10E, 110D	120
Large Electromechanical Assemblies	20–2000	120C	120
	1–2000	10E, 100D, 70C	180
	1–4000	10E, 120C, 50F	180
	20–5000	120C, 60F	180
	1–10,000	10E, 120C, 50G	180
	1–10,000	10E, 20D, 110C, 110F	240
	1–3000	10E, 150D, 55C, 25F	240
Small Components on Fixtures (Limited No. of critical resonances)	20–2000	60B	60
	20–5000	30A, 30G	60
	1–10,000	10E, 60B, 50G	120

Table 2. System Mixtures

Systems F and G are used to extend the upper frequency limit for high-frequency testing.

Typical applications, frequency ranges and filter system mixtures are further summarized in Table 2. Note that multiples of 60 filters are maintained in order to fully utilize one or more Equalizer/Analyzer chassis.

Table 2 illustrates the flexibility of the different filter systems, but is certainly not exhaustive in showing possible combinations.

Summary

In summary, AEROS provides the following advantageous features:

(1) Automatic narrow-bandwidth equalization for random or shock signal operation;
(2) Equalization held at any time by switch command;
(3) Maximum frequency range of 1-10000 Hz with 240 channels;
(4) Flexibility in choice of frequency range;
(5) Simple three-lamp display technique for each channel;
(6) Automatic test timing;
(7) Zero static error AGC circuits;
(8) AGC range greater than 60 dB (typically 70 dB);
(9) Critical controls interlocked during test;
(10) Built in vibration meter and signal filters;
(11) Low-drift active filters;
(12) Calibrated internal signal sources.

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3. PAINTER, G.W. and H.J. PARRY: "Simulating Flight Environment on an Electrodynamic Shaker", *Shock, Vibration and Associated Environments,* Vol. 33, 3, pp. 85-95, March 1964.

4. GOLDWATER, I.T. and J.D. HANSEN: "Automatic Shock Spectrum Synthesis and Analysis", *IES Proceedings,* pp. 407-11, 1970.

5. IRVINE, R.G.: "Real-Time, Wide-Band Shock Response Analysis", *IES Proceedings,* pp. 25-30, 1969.

6. RUBIN, S.: *Shock and Vibration Handbook,* Vol. 2, pp 23-11-21. McGraw Hill Book Co., 1961.

7. SHIPWAY, G.: "A New Technique for Seismic Shock Simulation", *Test Engineering,* Nov. 1970.

8. RUBIN, S.: *Shock and Vibration Handbook,* Vol. 2, p. 23, McGraw Hill Book Co., 1961.

Brief Communications

The intention of this section in the B & K Technical Review is to cover more practical aspects of the use of Brüel & Kjær instruments. It is meant to be an "open forum" for communication between the readers of the Review and our development and application laboratories. We therefore invite you to contribute to this communication whenever you have solved a measurement problem that you think may be of general interest to users of B & K equipment. The only restriction to contributions is that they should be as short as possible and preferably no longer than 3 typewritten pages (A 4).

Letter to the Editor

by

Dr. Th. Lange)*

A measuring method for the determination of the complex modulus of elasticity of fibres similar to the one described in Technical Review 1970 No. 2, p. 3 to 20, by B. Stisen has been developed and used in 1967/1968 at the physical laboratory of our Bobingen factory. In this method use is made of two accelerometers. The first accelerometer is attached to the vibrating mass of a 15 kg shaker and is used for a control signal to a compressor loop keeping the excitation level constant. The second accelerometer is attached to the mass suspended from the fibre (instead of the capacitive transducer used by Stisen).

The following advantages are achieved:

1. no cross talk

2. no DC voltage

3. no readjustment due to changes in fibre length.

Changes in fibre length due to plastic yield are inevitable, particularly when high preloads or high temperatures are being used.

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*)Farbwerke Hoechst A.G., Germany.

A variation of the method can be used for the automatic measurement of resonant frequency and thereby the determination of the modulus of elasticity. The voltage generated by the accelerometer suspended on the fibre under investigation is amplified and fed back to the power amplifier, via which the shaker is controlled. If the gain in the entire loop is adequate, the natural frequencies of the fibre with the suspended mass will be self-generating. The only thing left for determination of the modulus of elasticity is a frequency measurement. The advantage achieved by applying this variation of the method really becomes obvious, if the fibre temperature is changed. For this purpose the fibre is mounted in an environmental oven, the temperature of which increases throughout the test time. The oven used in our laboratory had forced hot air circulation.

A further application of the method is determination of the loss factor. According to this variation the power amplifier is switched off for a few seconds at regular intervals of time and thereby at various known fibre temperatures. By a logarithmic recorder the decreasing amplitude of the resonant oscillation will be recorded as straight line decay curves, the slope of which can be used for calculating the internal damping of the fibre.

The last mentioned variation of the measuring method revealed an interesting maximum of the loss factor between 100 and 200^{o} C. The method is also specially suited for measurements on multifilaments.

The cross-sectional area, as is well known, can be found by measuring the length of the fibre and then weighing it, this method being far more accurate than the determination by means of a microscope as used by B. Stisen.

News from the Factory

NEW INSTRUMENTS

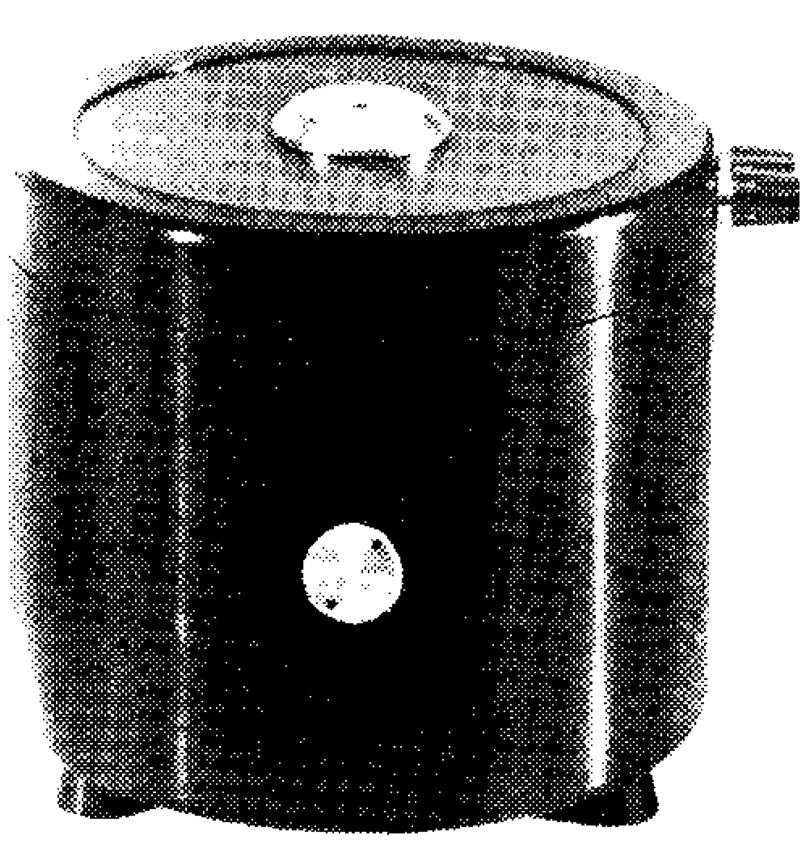
The new instruments shown on the following pages form a full range of vibration test equipment. Both a small shaker and two medium size vibration exciter systems are shown together with their power amplifiers.

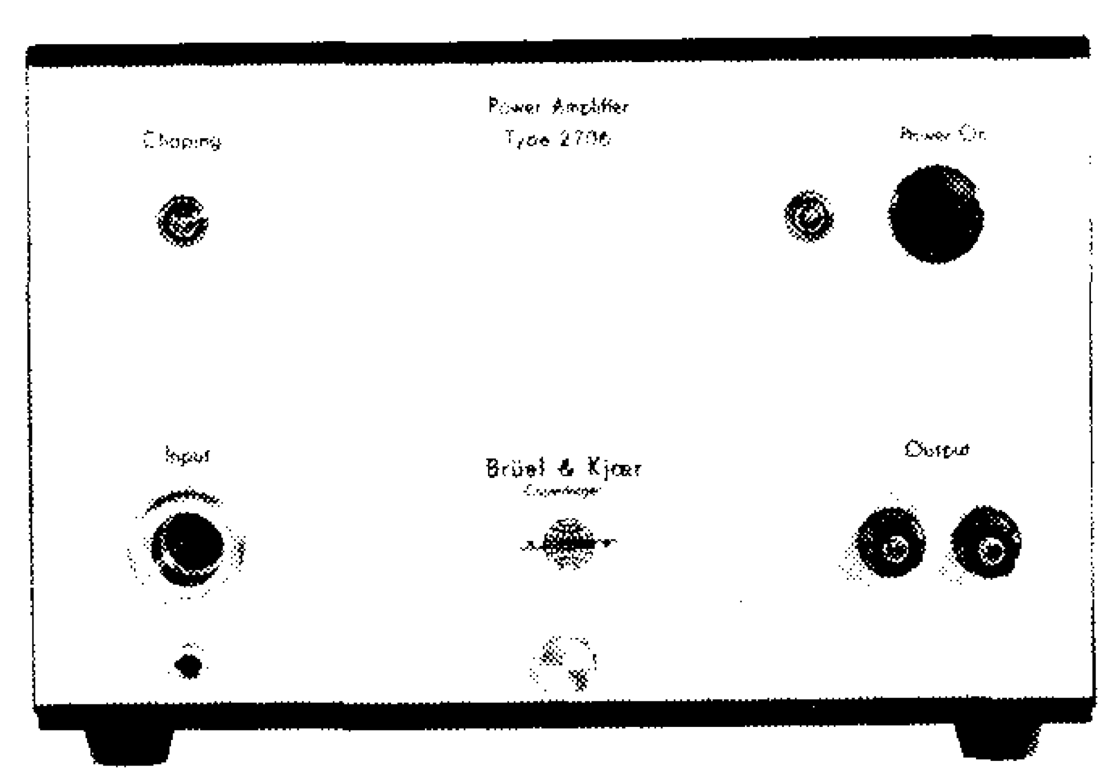
Two different exciter-controls are released, one providing sophisticated sweep sine and sweep narrow band random facilities and the other giving completely new automatic equalization and analysis possibilities of shaped spectrum of random and shock signals.

A new preamplifier allows application of a wide range of accelerometers, and a sensitivity comparator eases routine calibration of test accelerometers.

New accelerometers are provided for demanding calibration and test purposes.

Vibration Exciter Type 4809





The relatively high first axial resonance (20 kHz) makes the exciter a good choice for many applications with force requirement up to 44.5 Newton (10 pound) giving a peak acceleration of 75 g on bare table. If cooling is provided by means of compressed air (of sufficient purity) performance can be further improved.

At low frequencies operation is only limited by a peak velocity limit of 1.65 m/sec. (65 in/sec.) and a displacement limit of 8 mm peak-peak (0.31 in).

Cross motion and distortion are low in the operating range.

The Vibration Exciter is driven by a Type 2706 Power Amplifier.

Vibration Exciter Systems V and S

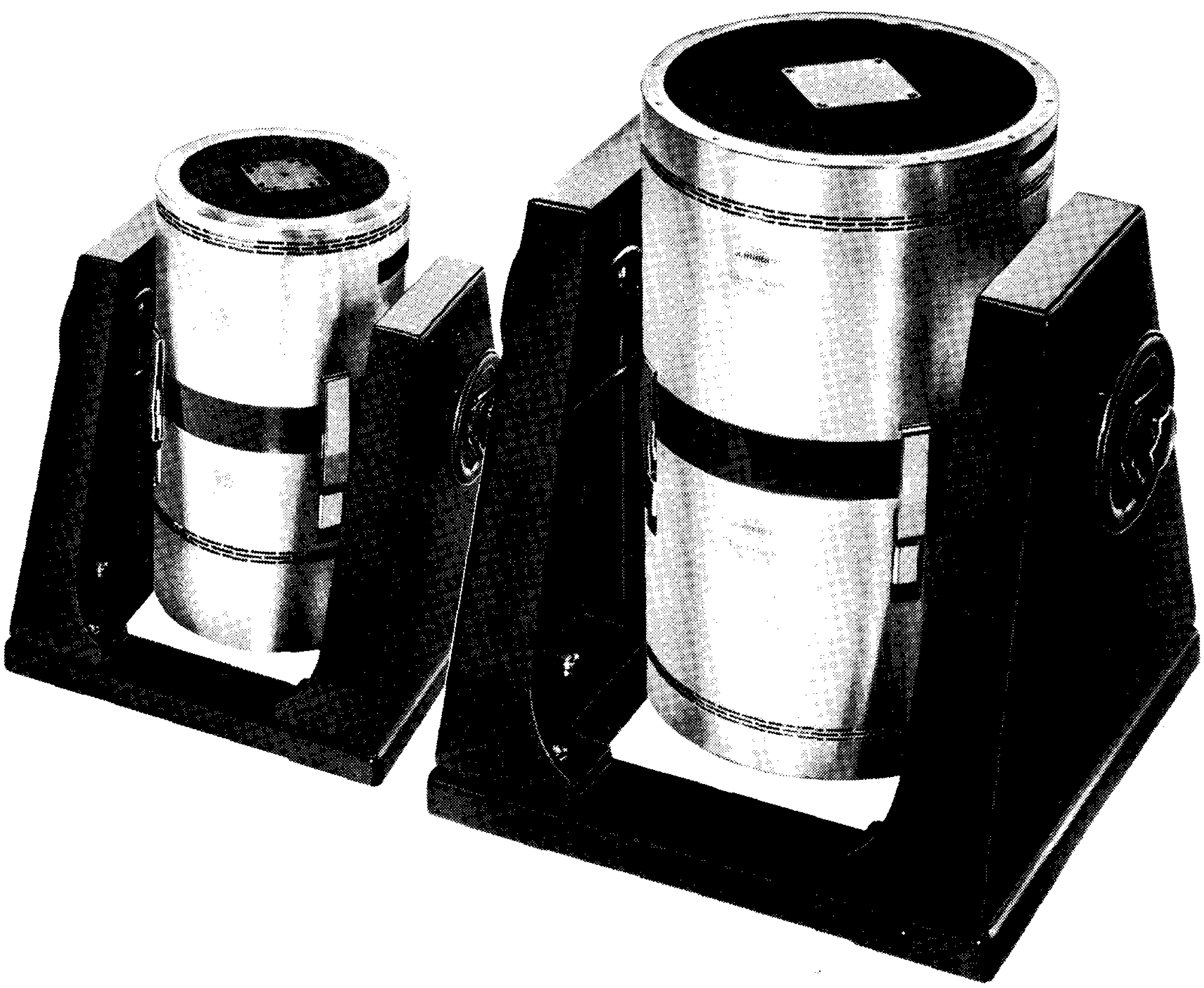
These Vibration Exciters cover small and medium force requirements in vibration testing. They deliver max. 445 Newton (100 pound) and 1780 Newton (400 pound) dynamic force for the V and S systems respectively.

Each exciter system consists of an Exciter Body and a number of easily interchangeable Exciter Heads.

The type numbers of the Exciter Bodies and Heads are shown in the table below.

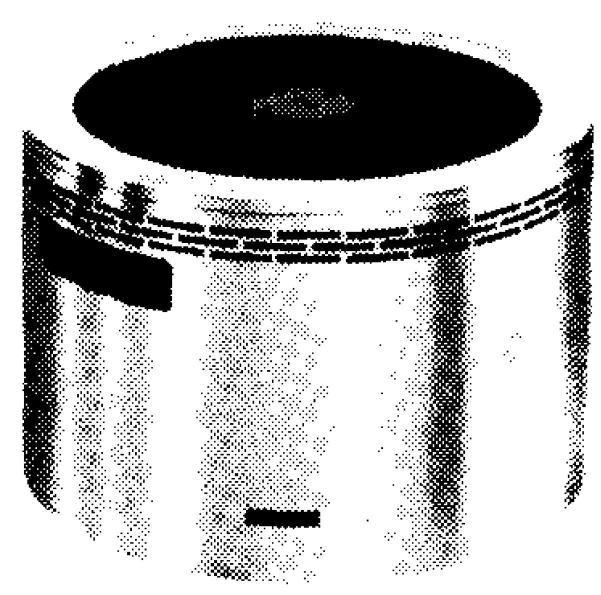
System		V	S
Exciter Base	Types	4801	4802
High g Head	-	4811	4816
General Purpose Head	-	4812	4817
Big Table Head	-	4813	4818
Mode Study Head	-	4814	4819
Calibration Head	-	4815	
Power Amplifier	-	2707	2708

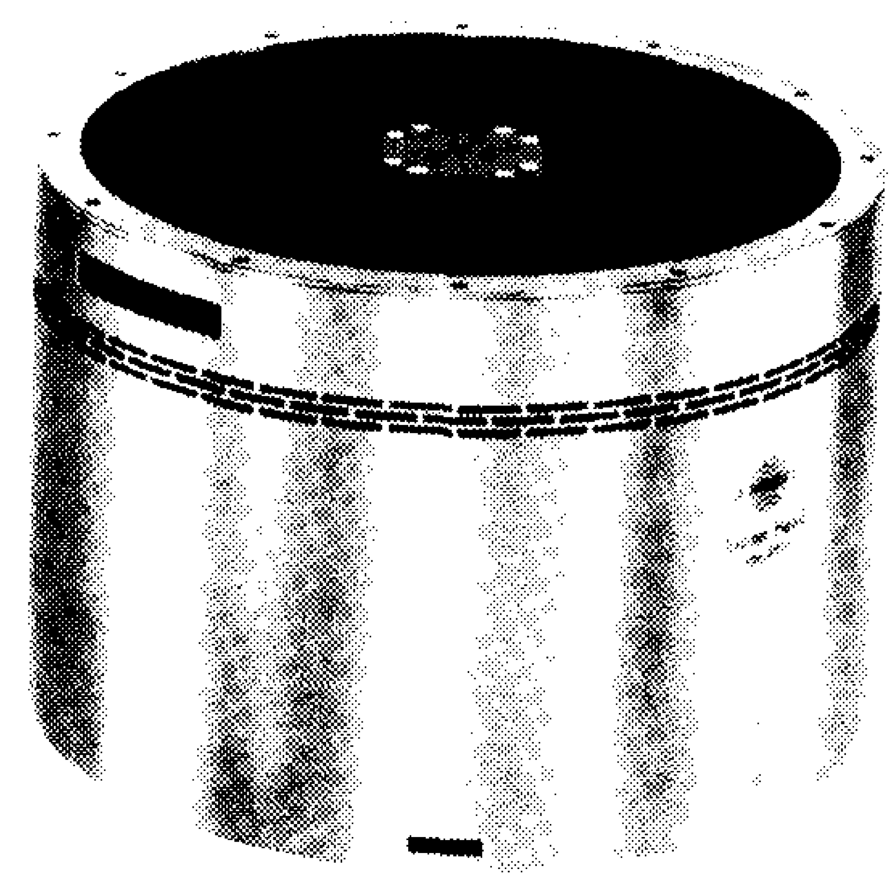
Exciter Body, Types 4801 and 4802



Each of the Exciter Bodies contains a magnetic field coil, its power supply and a blower which provides cooling air around the field coils and the moving coil of the Exciter Head. They are supported flexibly by a pedestal which can be bolted to a foundation designed for the actual exciter size and its applications.

High g Head, Types 4811 and 4816





These Heads have been designed for minimum moving mass with optimal rigidity, which has resulted in maximum attainable accelerations (with bare table) of 210 g and 240 g for the two types respectively.

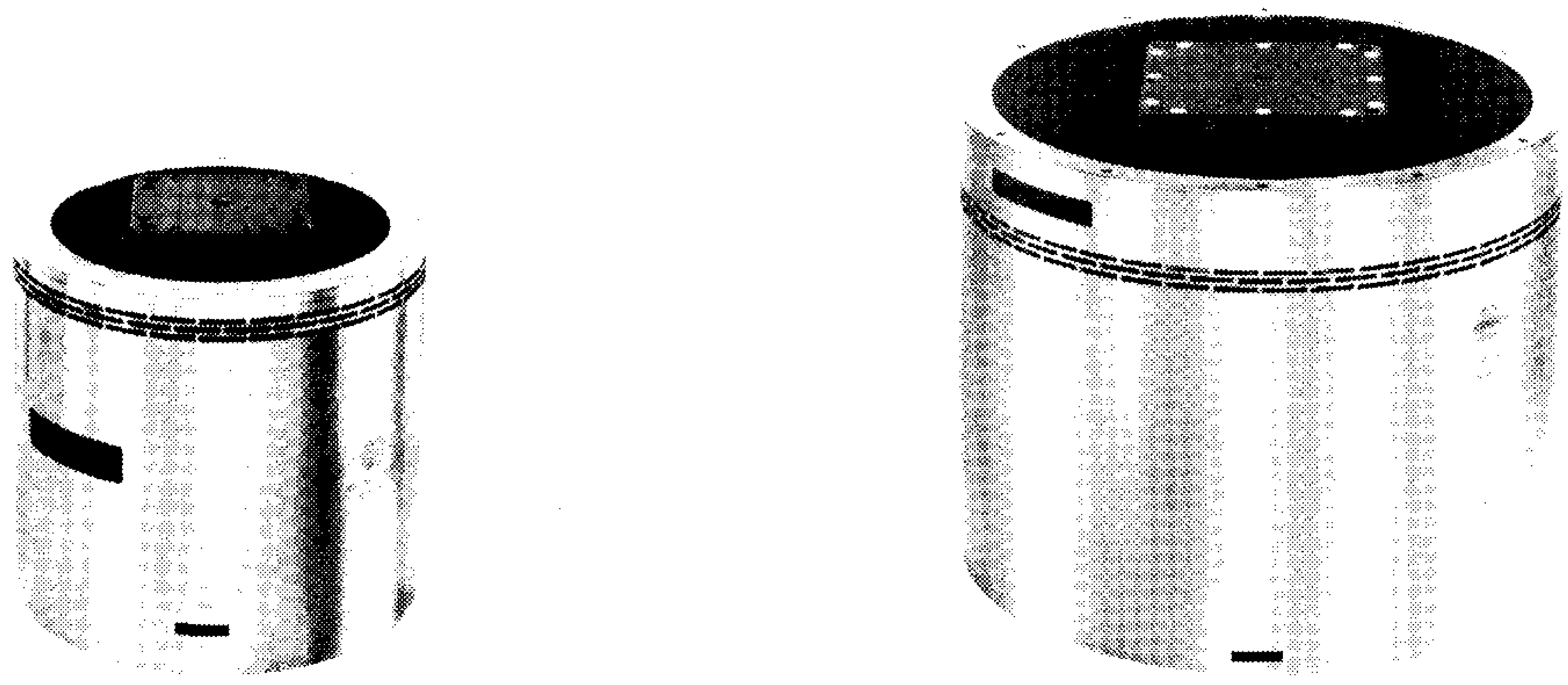
For maximum acceleration level, which is dependent on the load on the exciter table, operation is only limited by a peak velocity maximum of 50 in/sec. and a peak to peak displacement maximum of 0.5 and 0.75 inches for the two types respectively.

The displacement limit is the same for all the following heads except the Mode Study Heads for which the maximum displacements are larger. The first axial resonance for the two High g tables is at 8.5 and 5.3 kHz respectively.

General Purpose Head, Types 4812 and 4817
The General Purpose Heads have a more rigid construction than the High g Heads in order to facilitate larger objects to be tested. The design reduces maximum peak acceleration of the bare table to 100 and 148 g, and the frequencies of first resonances are 7.2 and 5.3 kHz, respectively. The specification for these Heads make them feasable for most normal shaker applications.

Big Table Head, Types 4813 and 4818
These heads are especially constructed to support heavy loads in both axial and radial direction. They are especially well suited when heavy loads must be vibrated horizontally without the support of a slip table.

The heavy and rigid construction of the moving system still allows max.



peak accelerations of 62.5 and 94 g and first resonances at 5.4 and 4.4 kHz respectively.

One feature should be mentioned: The table dimensions in the two systems are designed so that test rigs intended for a Big Table Head in the V system can be installed directly on a General Purpose Head in the S system if testing requires more force than first estimated.

In the table below are shown the threads of the fixing holes and the diametral distance between them.

For the fixing holes inserts (mechanical fuses) with different threads can be supplied, in order to facilitate all types of vibration fixtures.

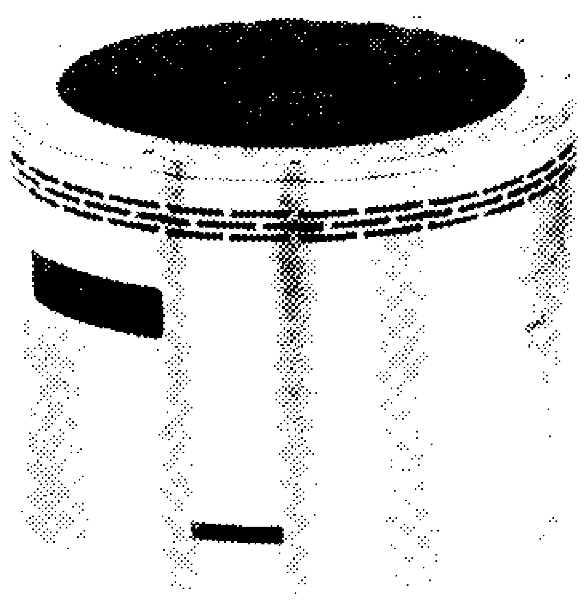
In the table below are shown the available threads of the inserts and the diametral distance between the fixing holes.

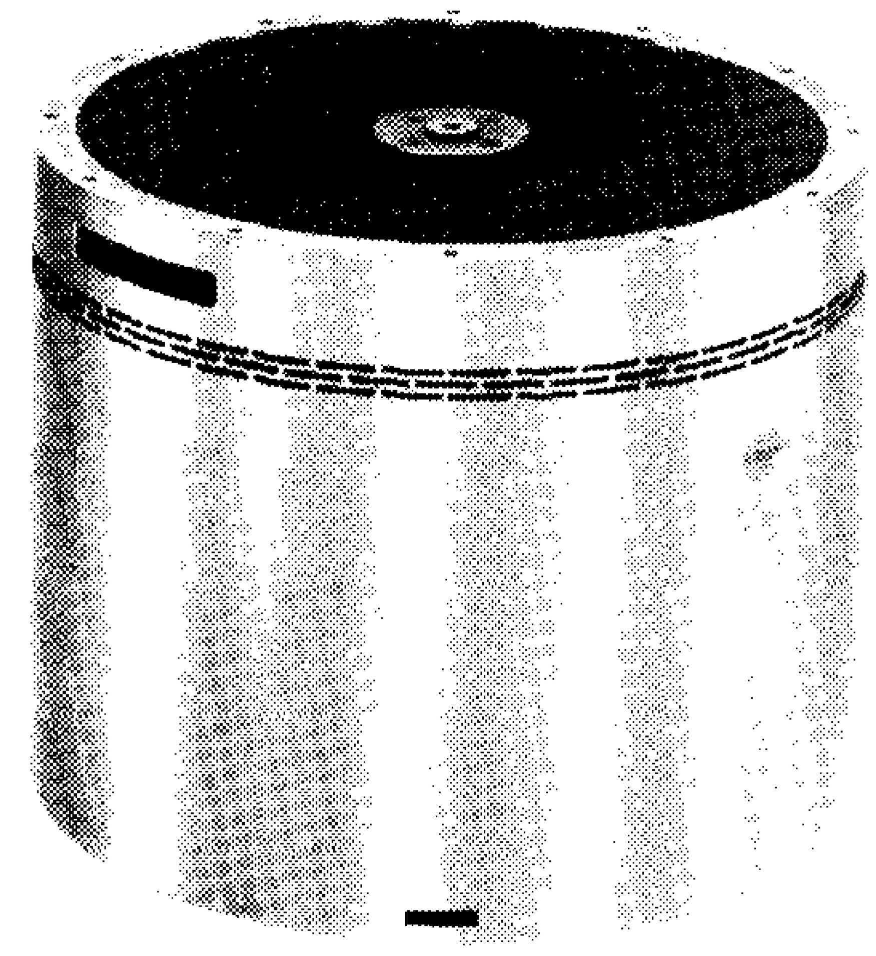
		V	S
High	Thread	8 – 32 UNC M4	10 – 32 UNF M5
	Diameter (inch)	2	3
General Purpose Head	Thread	10 – 32 UNF M5	1/4 – 20 UNC M6
	Diameter (inch)	3	4.5
Big Table Head	Thread	1/4 – 20 UNC M6	5/16 – 18 UNC M8
	Diameter (inch)	4.5	6.75

Mode Study Head, Types 4814 and 4819

The Mode Study Heads have been designed for large displacements with low distortion. The table motion is normally transferred to the structures to be tested by means of push rods or tension wires.

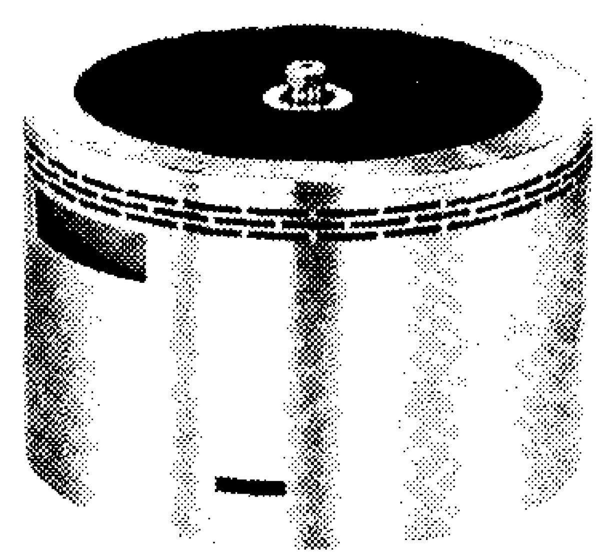
Max. displacements are 1 and 1.5 inches peak to peak, and first resonance occurs at 6.4 and 4.3 kHz respectively for the two heads.





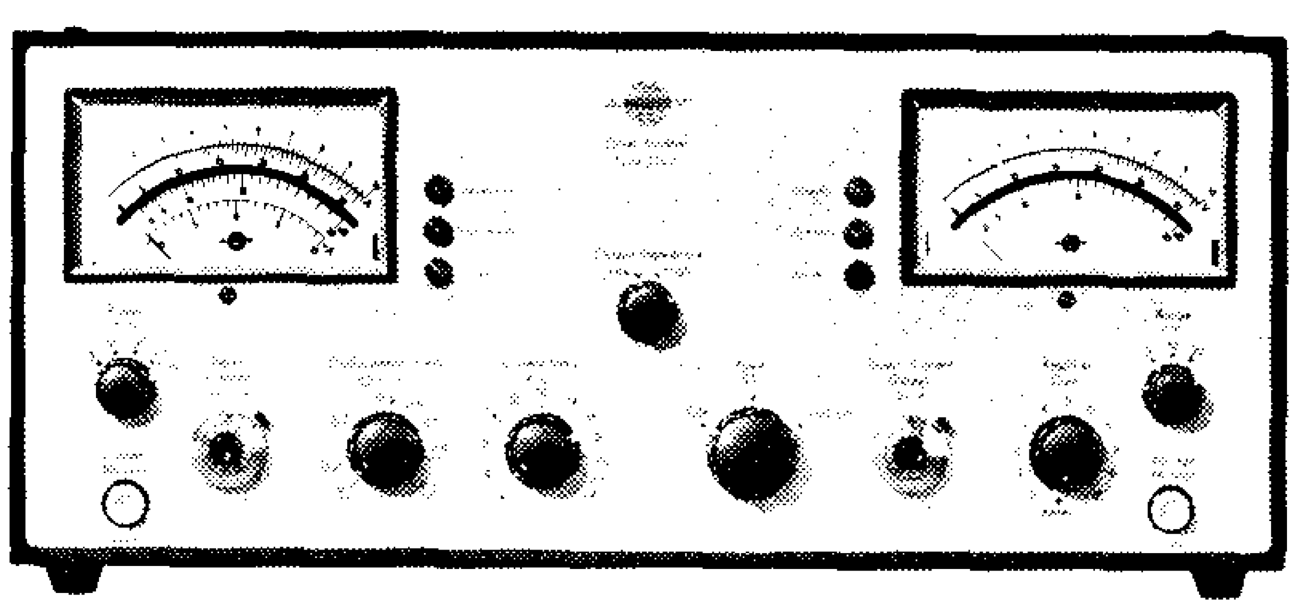
Calibration Head, Type 4815

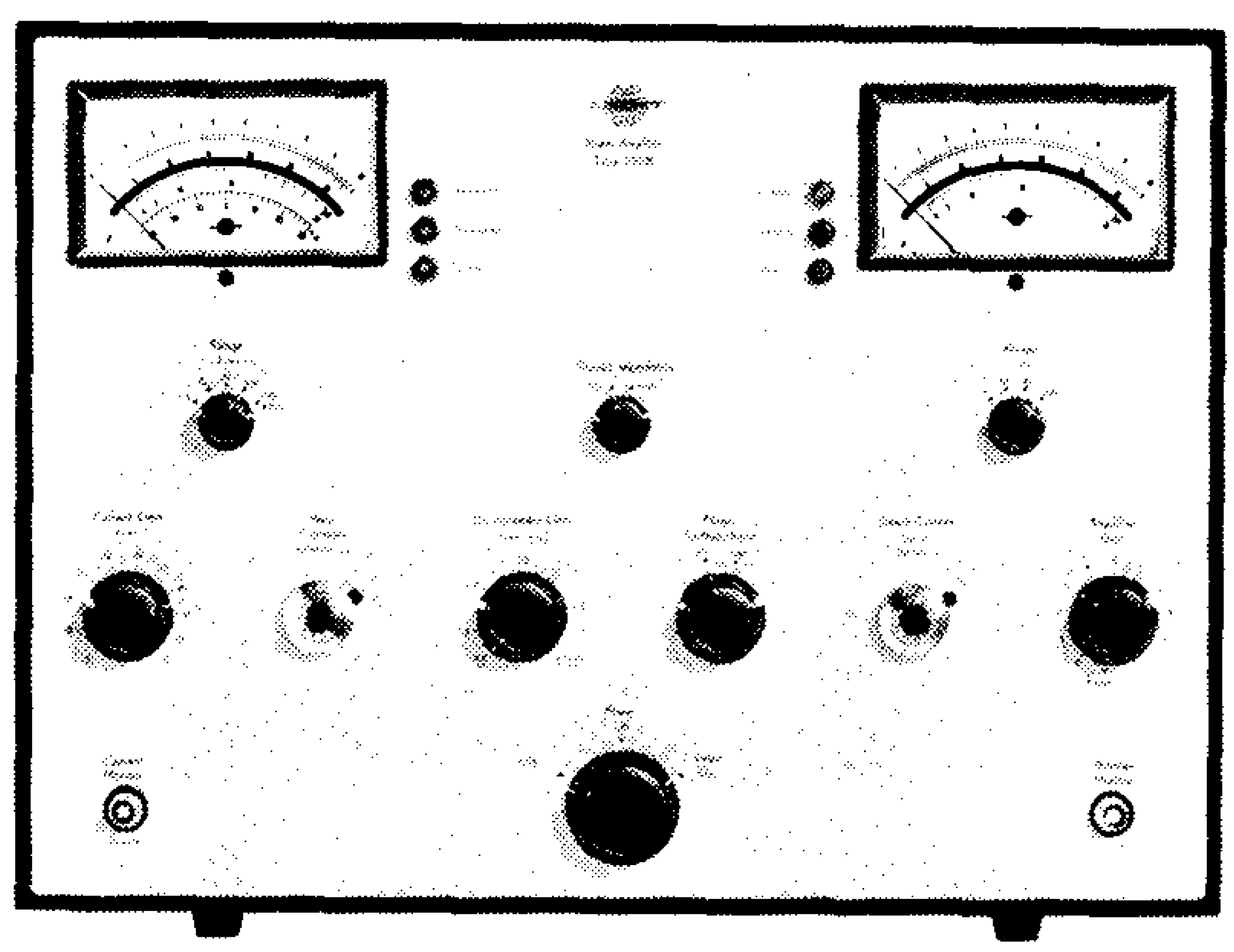
This head has been designed with the particular purpose of calibrating test accelerometers over the full acceleration and frequency ranges.



The calibration can be performed up to 113 g and up to 10 kHz. It is performed by comparison with a built-in reference accelerometer, for instance with the aid of the Type 2970 Sensitivity Comparator mentioned below.

Power Amplifier, Types 2707 and 2708





The moving coils of all the Exciter Heads have a resistance of o.5 Ohms. As both the two Power Amplifiers have been designed to supply this load, any Exciter Head can be driven from either of the Power Amplifiers.

This permits a combination of use of a S-Shaker with a 2707 Power Amplifier. The price of the system would then be between that of a V-Shaker and a 2707 Power Amplifier and that of a S-Shaker and a 2708 Power Amplifier.

The power ratings of the amplifiers are 220 and 1200 VA for the 2707 and 2708 respectively.

The frequency range is 0 – 100 kHz, but full power capacity is obtainable from 40 Hz – 5 kHz for 2708 and to 10 kHz for 2707.

The amplifiers have very low hum and harmonic distortion both in the high and the low output impedance modes.

They supply a variable DC voltage to provide a static force in either direction, on which the dynamic forces are superimposed.

A number of protective features ensure that no part of the vibration system is accidentally damaged.

When the preset limits for each of the following functions are exceeded, they are indicated by an appropriate red warning light, and the Power Amplifier cuts out the signal to the exciter coil automatically.

Table displacement
Exciter coil current
Transistor junction and heat sink temperature
Blower operation

Amber warning signals are given for

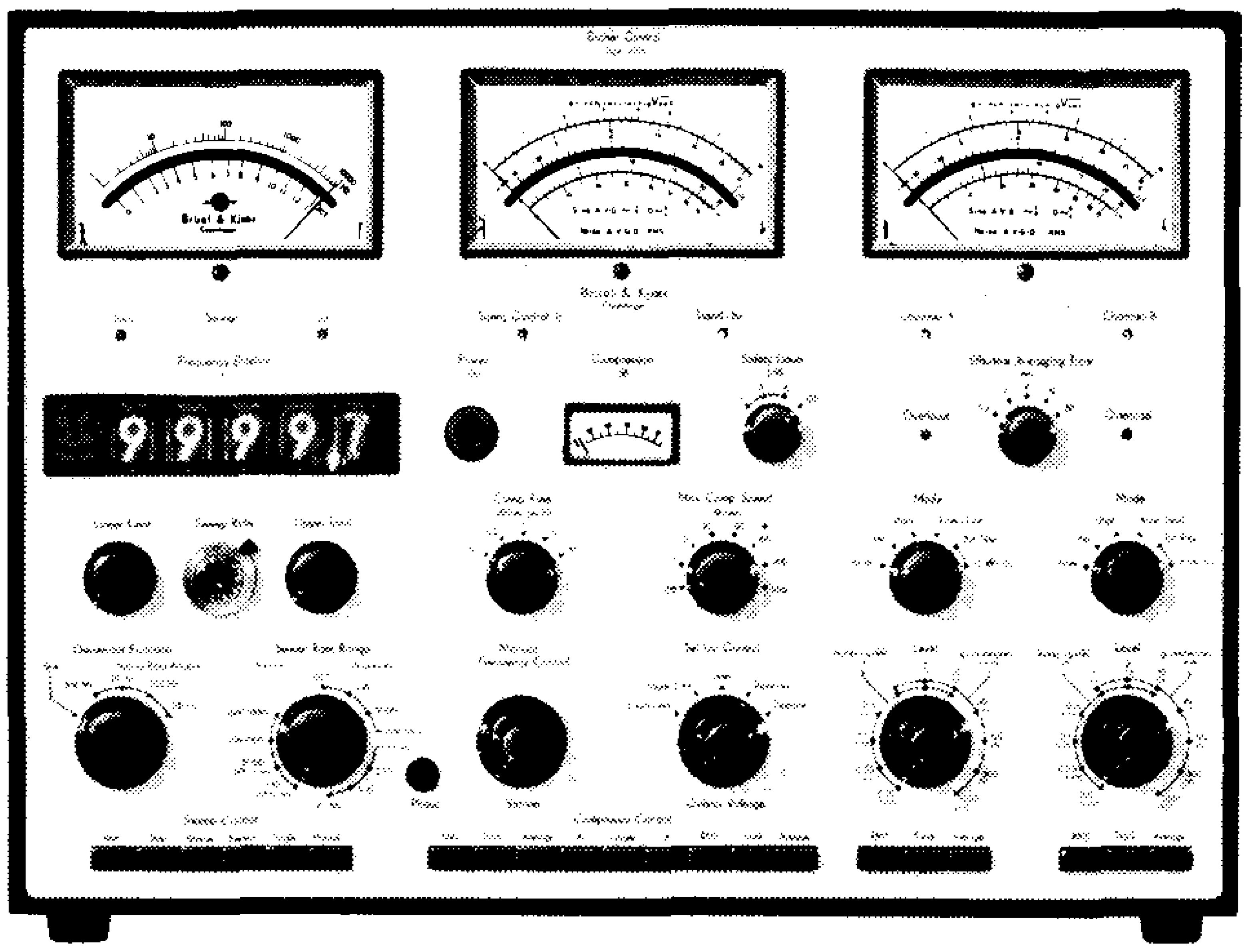
Signal clipping
Power transistor shorting

The Power Amplifiers can be driven by all B & K Vibration Exciter Controls including the new Exciter Control, Type 1026 and the Automatic Equalizer/Analyzer, Types 3379 and 3380, which are described below.

Exciter Control, Type 1026

The new Exciter Control is intended for use with all types of electrodynamic vibration exciters. It provides sine or narrow band random signals in the frequency range from 1 Hz to 10 kHz.

The sweep function is operated by an internal or an external ramp voltage



and several linear or logarithmic sweep rates can be selected. Output frequency is simultaneously monitored on a meter and a digital read-out.

For use with external recorders three separate outputs are provided, a DC proportional to frequency, a DC proportional to the logarithm of frequency, and a BCD-coded digital output.

Bandwidth change signals at 10, 30, 100, 300 and 1000 Hz are available for operation with the Type 2021 Heterodyne Slave Filter reviewed in Technical Review No. 4, 1970.

Two independent vibration meters are also provided, each giving a front panel meter output and a separate analogue output for use with a level recorder.

The compressor circuit of the generator section operates over an 80 dB dynamic range and is monitored by a compressor meter.

Either or the larger of the measuring channels can be chosen, by a push button selector, to control the compressor loop.

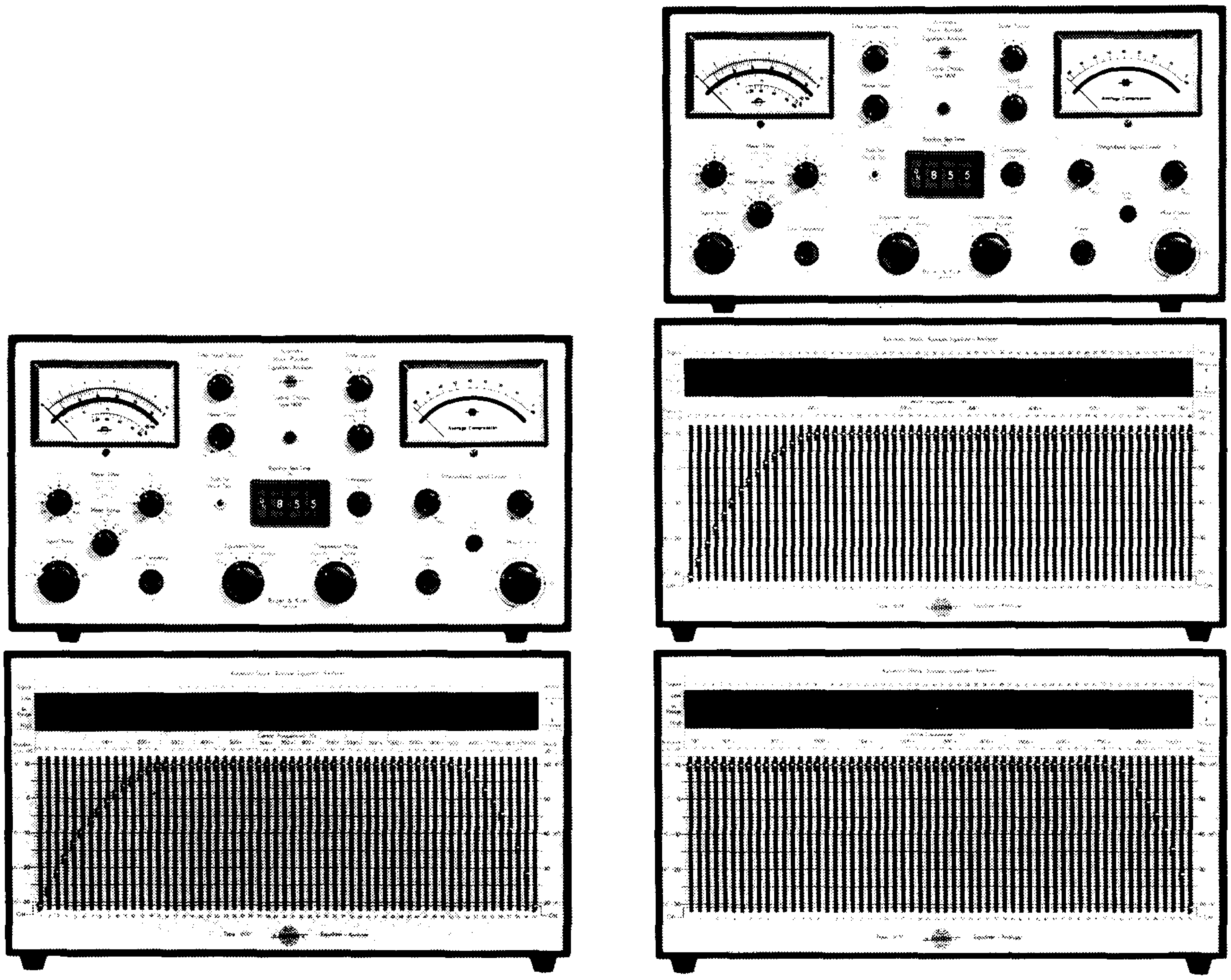
Compressor speed increases with frequency to a chosen maximum value between 1 and 1000 dB/sec. Different rates of increase can be selected from 0.1 dB/sec. times the generator frequency to infinity, in which case the chosen maximum compressor speed is valid over the entire frequency range.

Each measuring channel give a choice of acceleration, velocity, displacement or acceleration gradient measurements.

Four rectifier circuits allow the two meter readings and the two compressor channels to operate independently on a wide band RMS or average signal, or on a signal filtered by a 6% relative bandwidth tracking filter.

The Exciter Control uses lamps to indicate the operating modes and a fast-acting safety detector switches the generator to "Standby" if the compressor level changes by more than the preselected safety limit (± 1, ± 3, or ± 6 dB).

Automatic Shock-Random Equalizer-Analyzer, Types 3379 and 3380



The Automatic Equalizer-Analyzer systems provide a very useful solution to the problem of controlling (or analysing) a shaped random spectrum excitation or a well defined shock spectrum.

The two Equalizer-Analyzer systems now released are supplied with 60 parallel channels (the B filter system) Type 3379 or with 120 parallel channels (the C filter system) Type 3380.

Both systems cover the frequency range from 20 Hz to 2 kHz with filters of 10 to 50 Hz and 5 to 25 Hz 3 dB-bandwidth respectively.

The principle of operation (which is thoroughly treated by Dr. Usher in his article) is that a random noise or shock source is applied simultaneously to the input of all the parallel equalizer filters. Their outputs are added (after passing an automatic gain control circuit) and applied to the power amplifier of a shaker system.

The output from the control accelerometer is fed to the parallel-connected attenuators. The attenuators each feed two slider switches whereby the input signal to each analyzer filter can be attenuated individually over a 40 dB range in 1 dB steps. The output from each analyzer filter is rectified and led to control the corresponding automatic gain control in the equalizer circuit.

The level of the output signal in the filter bandwidth is thereby automatically regulated to the value selected by the attenuator. By adjusting all 60 or 120 slider switches complete regulation of the vibration spectrum can be maintained even if resonances of up to 60 dB exist in the mechanical test configuration. The operation of the servo loops is monitored by a simple lamp display, where a green light indicates for each channel that correct regulation is performed. Similarly, two red lamps for each channel indicate that the regulation signal level is outside the available regulation range.

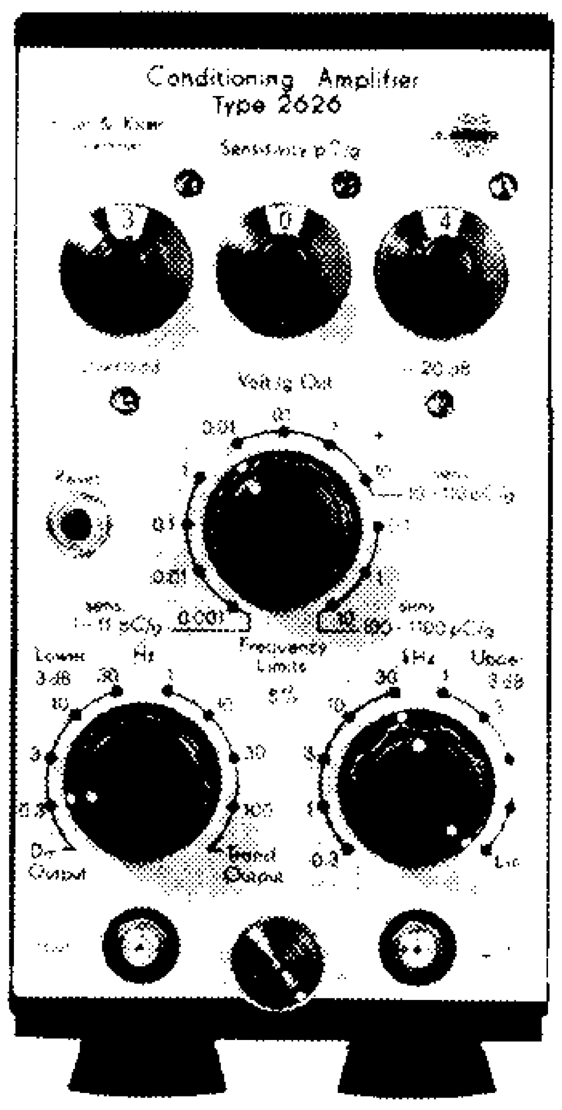
For shock operation the designed shock spectrum is adjusted on the attenuator panel and all equalizer filters are subjected to a repetitive voltage step. The resulting oscillatory voltages from the filters are added and applied to the shaker system at 20 dB reduced level. When equalization is complete for all filters the automatic gain circuit is locked in the "Hold" position and a full level shock can be applied.

The resulting signal is a fast swept sine pulse. This has the advantage that it allows much higher shock levels for a given exciter system than other waveforms with the same shock spectrum.

Furthermore, this type of oscillatory shock is often found in practical vibration environments.

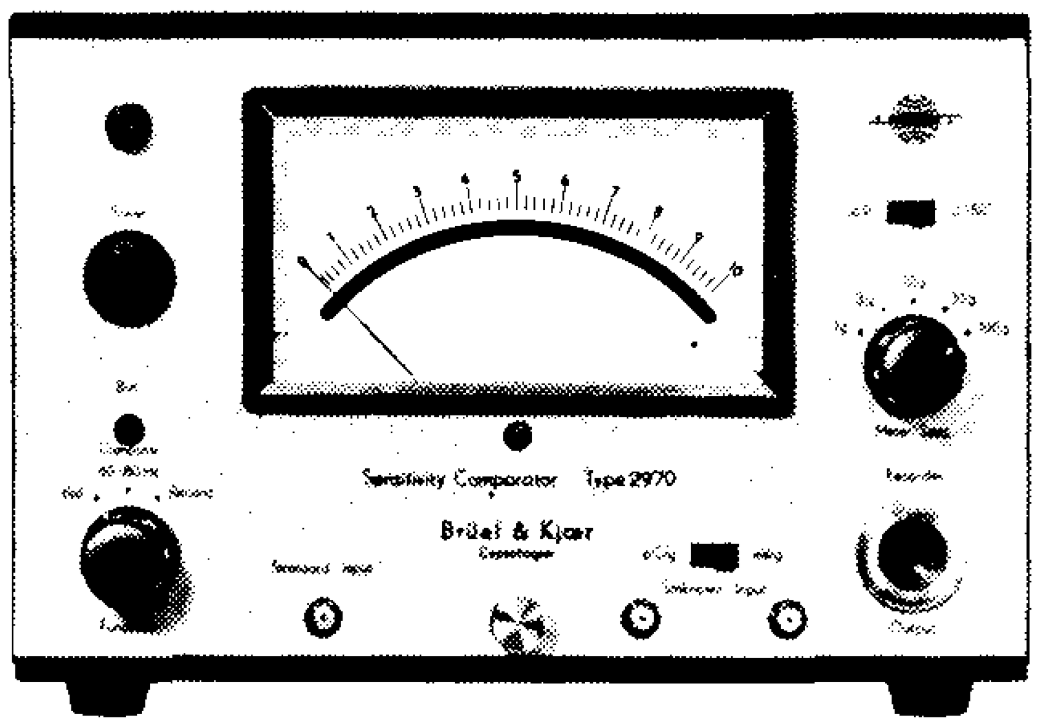
Conditioning Amplifier Type 2626
This charge sensitive accelerometer preamplifier is extremely well suited for applications where accelerometers with different sensitivities are used.

It has a maximum gain of 60 dB, and a 3 digit sensitivity setting adjusts the preamplifier for use with a large range of accelerometers. Direct reading of the transducer sensitivity, as well as the preamplifier output, eases its use with Vibration Meters and Exciter Controls of various types. Depending on accelerometer type the output can be chosen in steps from 1 mV/g to 10 V/g. Adjustable high and low pass filters render the Amplifier particularly well suited for use in servo loops for Vibration Exciters. Also the choice of direct output, or a floating transformer output will prove especially convenient for this application. Neon indicators warn for overload and for too low gain settings in which case the full dynamic range is not utilized.



Sensitivity Comparator Type 2970

The Type 2970 is designed to compare the sensitivity of an unknown accelerometer to that of a known reference accelerometer at vibration levels from 1 to 100 g.

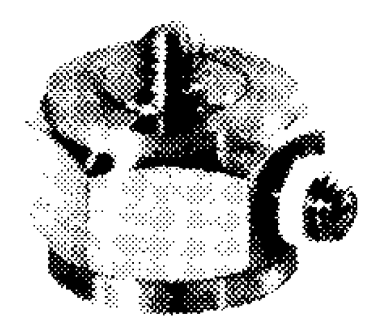


Normally, it should be used with two Conditioning Amplifiers Type 2626, arranged to give a nominal output of 10 mV/g. One is set to the reference accelerometer sensitivity, while the other is adjusted until minimum deflection of the Comparator Meter is obtained.

The unknown accelerometer sensitivity can then be directly read off the Conditioning Amplifier.

Force Transducer Type 8200

This transducer is designed to measure tensile and compressive forces in machinery and other constructions. Used with vibration exciters it can measure and control the applied force and be used for measurement of mechanical impedance in connection with an accelerometer.

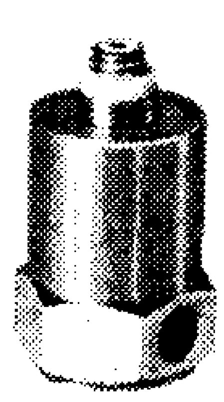


The transducer uses quartz as the sensitive element giving a very low sensitivity to temperature changes and temperature transients.

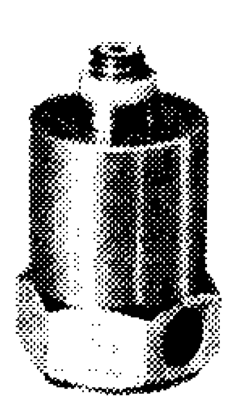
Preloading of the sensitive element ensures that the calibration values are valid for both tensile and compressive forces. A very high leakage resistance allows measurement down to extremely low frequencies when used with suitable preamplifiers.

As the internal capacitance of the transducer is only 25 pF, the force transducer should be used with charge amplifiers such as the B & K types 2624 and 2626. This secures a low lower limiting frequency and that influence on the sensitivity calibration by varying cable length is avoided.

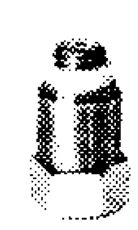
Piezoelectric Accelerometers Type 8301 and 8302



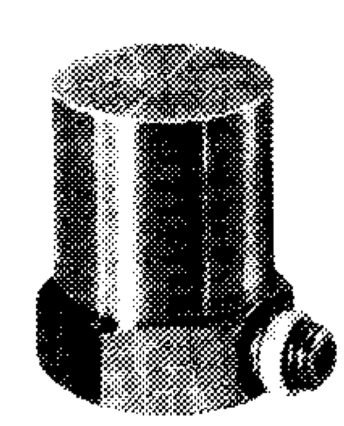
8301



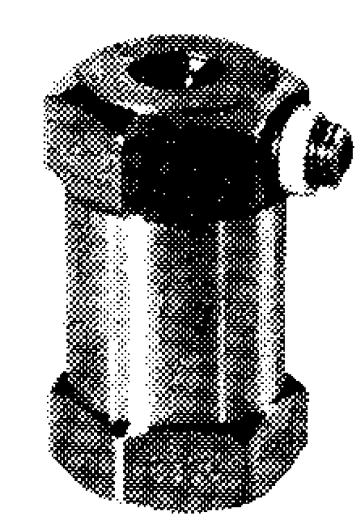
8302



8303



8304



8305

These Accelerometers are "Uni-Gain"® types: Type 8301 has a voltage sensitivity of 10 mV/g ±2% and Type 8302 has a charge sensitivity of 10 pC/g ± 2%.

They are inverted single ended compression types which ensures a low base strain sensitivity (of less than 5×10^{-4} g/μ strain). The design also includes provision for water cooling to allow measurements on hot surfaces up to 1000°C.

In addition heat insulation of the ceramic material has reduced temperature transient sensitivity to less than 4 g/°C.

In combination with low acoustic sensitivity the above features render Type 8301 and 8302 worth consideration for difficult applications at low frequencies.

Piezoelectric Accelerometer Type 8303
This miniature Acceleromter has a 10–32 NF top-mounted cable connection. This is achieved by "inverted single end" construction, which also provides low base strain sensitivity. Although this design increases weight compared to other miniature Accelerometer designs the free resonant frequency is 75 kHz rendering the useful high frequency limit to 9 kHz and 15 kHz for 2% and 10% error respectively.

Quartz Accelerometer Type 8304
This quartz accelerometer has been designed with the special intention of making a transducer with minimum sensitivity to temperature changes and temperature transients. A special construction gives a very low sensitivity to base strain and an all welded stainless steel construction makes it completely waterproof and ideally suited for use in very moist and corrosive atmospheres. The ceramic insulated, glass sealed input socket ensures complete sealing even after several times of temperature cycling up to 250^{o} C.

The accelerometer is calibrated in pC/g and should be used with the charge amplifiers Type 2624 or 2626. Due to the accelerometer's low sensitivity, the Type 2626 is recommended.

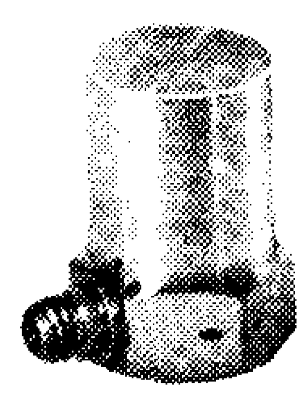
Accelerometer Reference Normal Type 8305
This accelerometer has been designed especially to allow calibration of accelerometers by the back to back method where the sensitivity of the investigated accelerometer is compared with that of the reference accelerometer.

The reference accelerometer Type 8305 is designed using quartz as the sensitive piezoelectric element which has a very high sensitivity stability to temperature changes and temperature transients. During production the utmost care has been taken to produce a transducer which is extremely stable in all its performance data so that it can serve as a reference for calibration of other accelerometers and of complete measuring arrangements. A special construction ensures very low sensitivity to base strain in both bases and an all welded stainless steel housing ensures minimum influence from moist and corrosive atmospheres.

The accelerometer has a 10 – 32 NF mounting thread in both ends, one in the base for mounting it on the shaker table and one in the top for the mounting of the accelerometer to be tested.

A polarity opposite to that of usual accelerometers allows a very simple calibration procedure as the amplification in one channel can be adjusted to give zero deflection when the two signals are added. Very simple calibration is also obtained using two Conditioning Amplifiers Type 2626 as the sensitivity of the accelerometer can be read directly from the gain setting of the amplifier when the two output signals are adjusted to be equal.

Accelerometer Type 4345



This accelerometer has been designed with the special intention of making a transducer suitable for vibration measurements at high temperatures. Typical application areas are with internal combustion and jet engines, for vibration monitoring, for example in power plants and in all kinds of experimental work.

The accelerometer is made of stainless steel and an all welded, hermetically sealed construction makes it suitable for use under severe environmental conditions. The input connector uses an aluminium oxide insulation material and the accelerometer is delivered with a silver screened cable, also withstanding temperature up to 400° C. The accelerometer cable is not sensitive to humidity and a new plug construction seals the connector when tightened. Both accelerometer and cable plug can be locked in their mounting position by means of a thin wire through holes in the accelerometer base and in the cable plug retaining nut respectively. This is of especial value when the accelerometers are used for vibration monitoring and for instance in airborne vehicles.

As the leakage resistance of the accelerometer decreases with increasing temperature it should be used with a charge amplifier in order to maintain a good low frequency response. Used with the Type 2624 Charge Preamplifier the low frequency response is that of the preamplifier up to the highest temperature (400° C).

PREVIOUSLY ISSUED NUMBERS OF BRÜEL & KJÆR TECHNICAL REVIEW

(Continued from cover page 2)

SPECIAL TECHNICAL LITERATURE

As shown on the back cover page Brüel & Kjær publish a variety of technical literature which can be obtained free of charge. The following literature is presently available:

Mechanical Vibration and Shock Measurements (English, German)
Acoustic Noise Measurements (English)
Architectural Acoustics (English)
Power Spectral Density Measurements and Frequency Analysis (English)
Standards, formulae and charts (English)
Lectures and exercises for educational purposes (a list of available papers is obtainable in English)
Instruction manuals (English, German, French, Russian)
Short Catalogue and Main Catalogue
Product Data Sheets (English, German, French, Russian)

Furthermore, back copies of the Technical Review can be supplied as shown in the list above. Older issues may be obtained provided they are still in stock.

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