THE General Radio EXPERIMENTER

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

THE VIBRATION METER — A NEW ELECTRONIC TOOL FOR INDUSTRY

Also IN THIS ISSUE

VIBRATION AND ITS MEASUREMENT

● **ALTHOUGH THE LOW-FREQUENCY LIMIT** of hearing for average individuals is about 16 cycles per second, frequencies lower than this can still cause considerable annoyance.

For instance, a man riding in an automobile may experience a sensation that he recognizes as either "noise" or "vibration," but which is really neither of these alone but a combination of the two. In the low-frequency region, vibrations may be felt at frequencies so low that they cannot be heard. This ability to feel the vibration through the sense of touch extends well up into the audible range and may be detected even

(*Continued on page 2*)

●**THE OFFICE OF PRODUCTION MANAGEMENT** requires that we make shipments on defense orders in accordance with their preference rating, and before shipments are made on any non-defense requirements for the same item. The great majority of orders now are for defense. Therefore, be sure to indicate the preference rating on all purchase orders. We will frequently have to request an official extension of the preference rating on the Priorities Division Form PD-3, but this will be done only when necessary for extension to subcontractors.

When an instrument is needed quickly we urge you to avoid the formality of asking for a quotation first before placing the order. The net prices, f.o.b. the factory, are given in the catalog or the *Experimenter*, and not infrequently we find that, although we can make delivery from stock when a quotation is made, the stock is exhausted when the order is received. That is why we are compelled under the present circumstances to make all delivery promises on quotations subject to prior sale.

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at very high frequencies when the amplitude of vibration is sufficient.

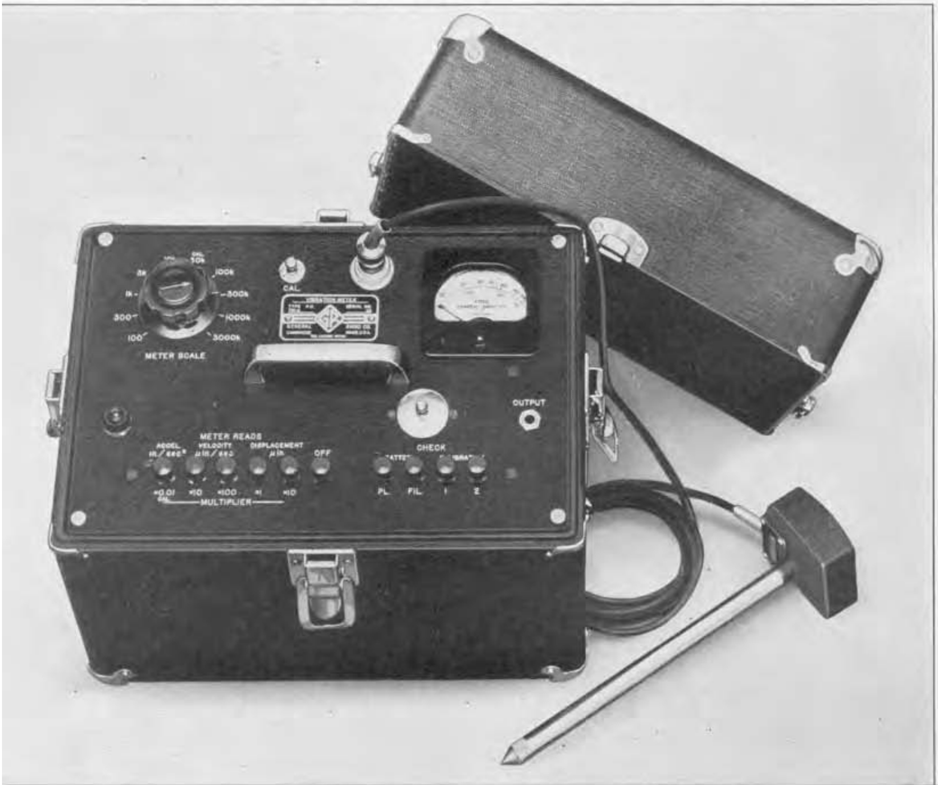
Sound, as generally encountered, is a vibration propagated through the air, but it is also transmitted through various other media and generally originates as an actual mechanical vibration in or of some solid structure. To trace noise to its source, therefore, through the many materials or mechanisms that may transmit it, some means of measuring vibration is desirable.

For some years sound and noise measurements have been increasing in importance to all branches of industry. A wide variety of mechanical devices, from clocks to automobiles, are checked with sound-level meters. The same type of meter is used for measurements on sound-absorbing and sound-insulating materials. Analyzers and various accessories have widened the scope of usefulness of this instrument, until today there are few engineering jobs which can be undertaken without some sort of sound-level measurements.

To adapt the sound-level meter to vibration measurement, a vibration pickup, replacing the microphone, can be used. Essentially, a vibration pickup is similar to a microphone, excepting that the pickup is designed to respond to solid-borne rather than air-borne vibrations. Hence, if the pickup is held in a sound field, the output, if any, will be relatively small compared to that of a microphone, but if it is held against some vibrating mechanical part, the output will be relatively high. This is essentially a matter of mechanical impedance and coupling.

The sound-level meter as a vibration-

FIGURE 1. View of the TYPE 761-A Vibration Meter with cover removed.



measuring instrument is limited in its frequency-response characteristics by the sound-level meter itself, and such instruments are seldom satisfactory below 25 cycles per second, although, for vibrations within the audible range, the vibration pickup has proved extremely useful. The need to extend the range of vibration measurements into the lower-frequency region, so that sub-audible vibrations can be measured, has led to the development of a new instrument, the TYPE 761-A Vibration Meter, which operates on the same principle as the sound-level meter.

The vibration meter as such does not replace the sound-level meter, but rather complements it. The two instruments cover overlapping frequency ranges, and throughout these ranges both types of measurement are useful. The vibration meter, like the sound-level meter, provides definite and reproducible readings, unaffected by human judgment, which are consequently invaluable for record and comparison purposes.

CHARACTERISTICS OF VIBRATION

The design of sound-level meters has been standardized and simplified through the general adoption by all manufacturers of the American Standards Association's tentative standards. These include frequency-response curves that approximate the characteristics of the human ear at various sound intensities, and, while these curves are not absolutely accurate for any particular individual, they represent an average of a large number of people. Hence the sound-level meter can be used not only to measure the physical characteristics of the sound, but also to approximate to a considerable degree the physiological and psychological effects.

The effects of vibration on human beings are less well known than those of sound, and, consequently, the main purpose of a vibration meter is to measure the actual physical magnitude of the vibration, while the problem of correlating such readings with the psychological and physiological effects is left to the user. It has not been found, however, that this presents any serious limitation to the use of vibration measurements, since for any particular problem the correlation between vibration and its undesirable effects can be determined relatively easily on an empirical basis.

The troubles arising from vibration can be generally divided into four classes, as follows: (1) noise, (2) annoyance, (3) deflection, (4) stress.

Under condition (1) the vibration is undesirable because of its resulting noise. This applies mainly to vibrations in the audible range and is the condition most generally associated in the public mind with the word "vibration."

Under the second condition the vibration is annoying in itself and is actually felt rather than heard, since it is mainly in the sub-audible range. This again is rather frequently encountered. A good illustration of this is found when standing on an upper deck at the stern of a steamship, where little noise is noticeable but where considerable vibration may generally be felt.

The third condition occurs when the vibration causes a deflection of certain members in the vibrating structure or mechanism, resulting in actual contact or striking, with consequent noise or breakage. This is a very severe condition, which obviously should never be encountered in finished mechanical designs, but it is frequently met in the laboratory where design work is in progress.

Under the fourth condition the actual

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stresses set up in mechanical members of the vibrating machine cause a strain so severe as to exceed the elastic limits of certain mechanical parts, thus causing failure. This again is generally a design problem rather than one encountered in the field. Such conditions are usually encountered in equipment which must be built to the very closest limits of safety in order to save weight or size, as in airplane design.

Obviously, the characteristics of most simple vibrations can be satisfactorily described through measurements of amplitude and frequency, and in advance design work such measurements are generally required. In more simple cases, however, it is desirable to obtain a single figure which expresses reasonably well the characteristics of the vibration, and, with this idea in mind, various types of vibration-measuring devices have been used at one time or another. Such devices have generally read one of three characteristics of the vibration — namely, displacement, velocity, or acceleration — depending mainly upon the inherent characteristics of the particular vibration-measuring device.

In the design of a new and universal type of vibration meter, selection of any one of these three characteristics as standard did not seem desirable, any more than in the design of a sound-level meter only one weighting characteristic would be desirable. Under a particular condition any of the three types of vibration measurements might be the best.

The displacement of a vibration is, of course, merely a measure of the actual amplitude, without respect to frequency, and is of importance mainly under conditions (2) and (3), as outlined above. Under other circumstances some definite relationship between the frequency and the magnitude of the vibration is desirable in the reading, and the choice between velocity and acceleration characteristics is based upon both practical and mathematical considerations. The velocity, being the derivative of the displacement, differs from it by a factor proportional to the frequency, while the acceleration, being the second derivative of the displacement, differs from it by a factor propor-

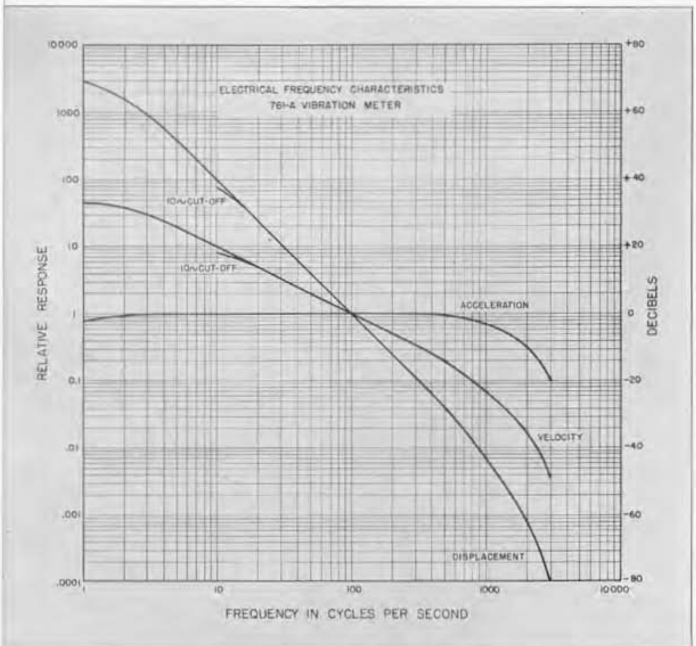

FIGURE 2. Frequency response of the electrical circuits in the TYPE 761-A Vibration Meter.

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tional to the square of the frequency.

In particular, velocity measurements have been found most useful under conditions (1) and (2) and give a good indication of the actual amount of noise caused by a vibration when the radiating surfaces are large compared to the wavelength of the vibration. Acceleration measurements are useful under conditions (1) and (4). So far as noise is concerned [condition (1)], acceleration measurements are most valuable when the radiating surfaces are small compared to the wavelength of the sound. Since the stress in any particular part will vary directly with the acceleration, it is obvious that this is the type of measurement to be used under condition (4).

DESIGN FEATURES OF THE VIBRATION METER

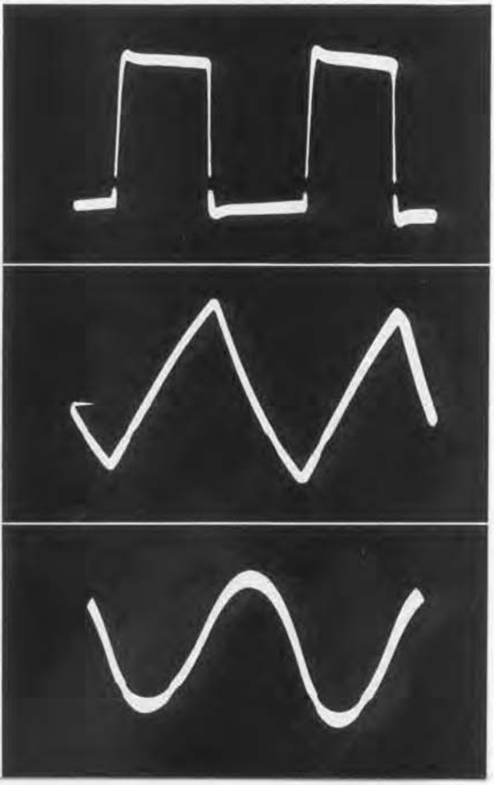
Heretofore vibration meters have generally been designed with only one or two particular applications in mind. In many cases the design of the meter has been influenced more by what was readily achievable in the way of response characteristic, rather than by what was needed for actual practical use. Hence there have been vibration accelerometers, vibration velocity meters, and vibration displacement meters, but few if any instruments have combined all three of these characteristics.

The need for inclusion of all three characteristics was first met by a special control box and vibration pickup designed for use with the General Radio Sound-Level Meter. This equipment, which has been available for several years,[1] consists essentially of a two-stage integrating circuit, which, when operated in conjunction with an acceleration-type pickup, provides a choice of acceleration, velocity, or displacement response over the frequency range of the sound-level meter.

Of primary importance in the design of a new vibration meter was the inclusion of all three response characteristics and extension of the frequency range well below the audible limit, in order to cover the range in which most of the important machinery vibrations are found. This involved considerably more than a mere redesign of the sound-level meter, although all of the essential and

[1]The Type 759-P15 Vibration Pickup and Type 759-P16 Control Box are for use with the Type 759-A Sound-Level Meter, and the Type 759-P35 Vibration Pickup and Type 759-P36 Control Box for use with the Type 759-B Sound-Level Meter.

Figure 3. The action of the integrating circuits is shown by these oscillograms of the output voltage of the vibration meter for the three types of response when a square wave is applied to the input. At the top is shown the displacement response with wave shape unaltered; the velocity is shown at the center; and the lower oscillogram shows the acceleration.



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desirable features of its mechanical and electrical design have been retained. The new instrument has been designed for useful response down to a lower limit of 2 cycles per second, and the integrating circuits are built into the amplifier itself rather than added at the input, thus minimizing the effects of tube noise, microphonic vibration, etc., and making possible the use of the instrument over a wide range of vibration amplitudes.

Figure 2 shows the actual frequency response of the electrical circuits of the vibration meter and demonstrates more clearly than words the unusual features of the design. Since the vibration pickup is of the acceleration type, the response must vary inversely as the square of the frequency in order to provide an over-all flat displacement characteristic, and this type of response must be maintained from the lower limit of 2 cycles up above the range of the vibration pickup. The amplifier circuit used is similar to the self-stabilizing circuit already in use in the Types 759-A and 759-B Sound-Level Meters, but with such changes as are necessary to produce the extended low-frequency response and to provide stability and freedom from unwanted regeneration or degeneration in the extreme low-frequency ranges.

An interesting example of the function of the integrating circuits is shown in Figure 3, which shows the output voltage for the instrument when a square wave is applied to the input terminals for the three types of response. The actual over-all frequency response of the instrument, including the vibration-pickup unit, is shown in Figure 4.

Figure 1 shows the appearance of the complete vibration meter and is ample proof of the high degree of simplicity and convenience which have been attained. The vibration values are read directly from the scale of the indicating instrument, and the sensitivity is adjustable over a wide range by means of the knob marked METER SCALE. The actual range covered between the smallest vibration which can be detected and the greatest which the instrument will indicate is 300,000 : 1[2].

The row of push buttons at the lower

[2] 3,000,000 : 1 for frequencies above 10 cycles.

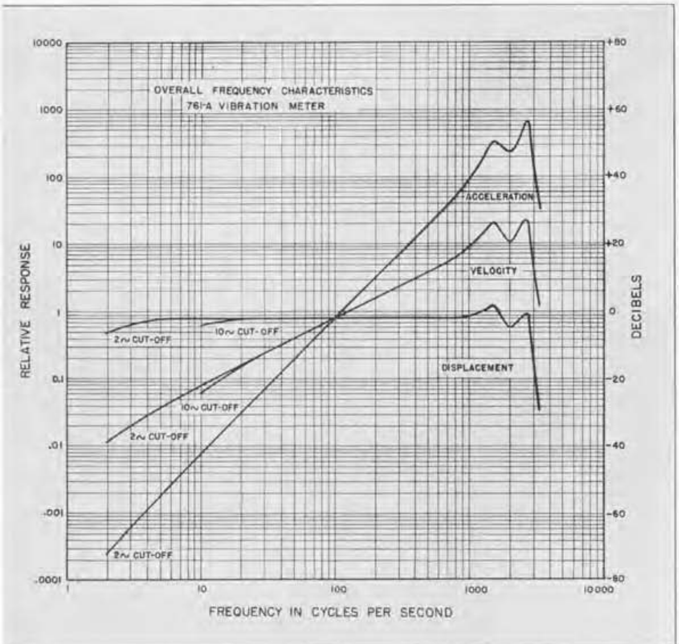

FIGURE 4. Over-all frequency response of the vibration meter, including the vibration pickup.

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edge of the panel provides all the additional controls necessary in the operation of the vibration meter. The meter is automatically turned on when any of the ACCELERATION, VELOCITY, or DISPLACEMENT buttons is depressed. These buttons control the response characteristic of the meter, as previously outlined. It will be noted that two each are provided for the velocity and displacement characteristics. In both of these cases the additional button provides an extra degree of sensitivity over what could otherwise be attained, through the expedient of limiting the low-frequency response below 10 cycles. The extra buttons, therefore, do not affect the normal operation of the instrument in any way, but provide an additional tenfold increase in sensitivity for use at vibration frequencies above 10 cycles. It will be noted that each of the buttons is marked with a multiplying factor to be applied to the meter readings when that particular button is used. The circuit values have been so chosen that the multiplying factors are all equal decimal units, so that multiplying becomes merely a matter of shifting a decimal point.

The four buttons at the right-hand end of the panel provide means for checking the accuracy of the instrument at any time. The PL and FIL buttons provide battery checks. For satisfactory operation it is merely necessary that the batteries provide a meter deflection above the B mark. The other two buttons, marked CALIBRATION, control an internal calibrating circuit which allows the amplifying circuit to be set accurately at any time to the original factory adjustment by comparing the gain with the loss in a fixed attenuator. In use, this is accomplished by connecting the instrument to a power line (60 cycles or any other power-line frequency), setting the other panel controls as indicated by the engraved words CAL, and pressing first CALIBRATION button No. 1 and then No. 2. If the gain in the amplifier is correct, the meter will show the same deflection when either button is depressed. If the two deflections differ, the sensitivity may be readily readjusted by means of a screw driver inserted in the opening just above the name plate. This calibration depends only upon the internal attenuator and is independent of the voltage or frequency of the power line.

The jack marked OUTPUT connects directly to a separate output amplifying stage entirely distinct from that which drives the indicating instrument. When the vibrations are in the audible range, a pair of phones plugged into this jack will provide a means of listening. The jack may also be used for connecting to an analyzer, recorder, or other auxiliary equipment. The external circuit connected to the output jack will have no effect on the operation of the meter.

Users of the TYPE 759 Sound-Level Meters will readily recognize similarities between those instruments and the new vibration meter. In the design of the new instrument full advantage has been taken of the experience gained in building hundreds of sound-level meters. The rubber suspension for the tube shelf, the compensated circuit to minimize the effects of battery voltages, the design of the attenuators, the shaped-pole-piece indicating instrument, etc., follow the same practice as in the widely used General Radio Sound-Level Meters. The same type of battery is used, and a similar type of airplane-luggage case. Provision is made in the cover of the case for holding the vibration pickup with spare tips and probe.

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USE OF THE VIBRATION METER

In use the vibration meter has exceeded all expectations. The ease with which readings may be taken, the provision of the three characteristics — namely, acceleration, velocity, and displacement — and the extension of the range down to 2 cycles per second with substantially flat response characteristics provide a degree of flexibility hitherto unapproached in commercially available vibration-measuring apparatus. It has already been applied to a wide range of applications, in the manufacture and design of airplanes, automobiles, and various mechanical devices, both large and small, and in the study of vibrations in structures.

— H. H. Scott

The price of Type 761-A Vibration Meter is $260.00, net, f. o. b. Cambridge. Complete specifications will be sent upon request.

SERVICE AND MAINTENANCE NOTES TO BE AVAILABLE

● CONSIDERABLE INTEREST has been shown in the article in the September-October, 1940, *General Radio Experimenter* which outlined a maintenance and service program for General Radio instruments. The number of requests that have been received for maintenance notes on particular instruments suggests that such notes would be welcomed by most General Radio customers. As a consequence, we are preparing comprehensive maintenance and service notes for a number of our most commonly used instruments. We are planning to send these notes, as they become available, to those customers who indicate an interest in them. If service and maintenance notes are desired, please write to the Service Department, specifying the type and serial numbers of your instruments. To obtain the maximum benefit from this program, it would be helpful if you could suggest to us the individual or group in your organization to whom such notes will be most useful.

We believe that this program will eventually result in longer life, improved reliability, and lower service costs for your General Radio instruments and parts.

— H. H. Dawes

ERRATA—TYPE 774 COAXIAL CONNECTORS

● TYPE 774-R1 and Type 774-R2 Patch Cords were incorrectly described in the April issue of the *Experimenter*. Type 774-R1 has a plug unit at one end and a jack at the other, while Type 774-R2 has a jack at each end.

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