MEASUREMENT

OF

VIBRATION

by

ERVIN E. GROSS, Jr.
Engineer, General Radio Company

GENERAL RADIO COMPANY

275 MASSACHUSETTS AVENUE

CAMBRIDGE 39 MASSACHUSETTS

90 West Street
New York 6, New York

8055 13th Street
Silver Spring, Maryland

1150 York Road
Abington, Pennsylvania

920 South Michigan Avenue
Chicago 5, Illinois

1000 North Seward Street
Los Angeles 38, California

Form 900-A

Printed in U.S.A

TABLE OF CONTENTS

ACKNOWLEDGMENT

Many of the author's associates have contributed in numerous ways in the preparation of this booklet. Much credit is due users of General Radio Company vibration-measuring equipment whose questions and application suggestions have determined to a large degree the contents and its arrangement.

The material in this booklet has been derived in many cases from previously published information and is referenced in the footnotes throughout the manuscript.

Grateful acknowledgment is made to Charles E. Worthen and Martin A. Gilman of the General Radio Company for their task of editing and preparing this material for the printers, and to Arnold P. G. Peterson of the General Radio Company and George Kamperman of Bolt, Beranek & Newman, Incorporated, for their contributions and useful and helpful suggestions.

E. E. Gross

CHAPTER I

INTRODUCTION

Vibration is the term used to describe continuing or steady-state periodic motion. The motion may be simple harmonic motion like that of a pendulum, or it may be very complex like a ride in the "whip" at an amusement park. The motion may involve tiny air particles which produce sound when the rate of vibration is in the audible frequency range (20 to 20,000 cps), or it may involve, wholly or in part, structures found in vacuum tubes, bridges, or battleships. Usually the word vibration is used to describe motions of these latter types and is classed as solid-borne, or mechanical, vibration.

Most of the important mechanical vibrations lie in the frequency range of 1 or 2 cps to 2,000 cps (60 to 120,000 rpm). In some specialized fields, however, both lower and higher frequencies are important. For example, in seismological work, vibration studies may extend down to a small fraction of a cycle per second, while in loud speaker cone design and studies of sub-miniature vacuum tube elements, vibrations at frequencies up to 20,000 cps must be studied.

There are several important effects of unwanted vibration in mechanical systems that make it desirable for us to study it and, if possible, to reduce it.

(1) Noise is created by the transmission of solid-borne audio frequency vibrations to air. Hence, the process of quieting a machine or device includes a study of the mechanical vibrations involved.

(2) Human discomfort and fatigue result when vehicles subject the passenger and operator to excessive vibration. Hence, vibration studies are an essential part of the development program for streetcars, trains, busses, boats, airplanes, and automobiles.

(3) Serious vibration can cause actual failure of structural materials which, in the cases of heavy machinery or airplanes for instance, can have fatal consequences.

Vibration, then, is not only a source of noise, annoyance, and discomfort but often a source of real danger. The present perfection of high-speed planes, ships, and automobiles could never have been achieved without thorough measurement and study of mechanical vibration.

There are, on the other hand, many important applications of controlled vibration. Tiny vibrators attached to instrument panels are being used to overcome pivot friction of indicating meters. Electrical and pneumatic vibrators of numerous shapes and sizes are being used as hopper shakers in material-handling applications. Electro-dynamic shakers or vibration exciters are made in a number of sizes ranging from small units for calibrating small vibration pickups and exciting lightweight specimens such as sub-miniature vacuum tubes to giant units weighing six tons and more used to test large assembled mechanisms and heavy components. These vibration exciters serve to test components and structures under controlled conditions.

In the design and adjustment of these vibrating systems, it is necessary to make the same types of measurements as in the study of unwanted vibrations.

It is the purpose of this booklet to introduce the reader to the common vibration terms, to describe a general purpose vibration measuring instrument with a number of useful accessories, and to outline how this equipment is used in typical measuring applications.

CHAPTER II

VIBRATION TERMS—THEIR MEANINGS AND USES

Displacement, Velocity, and Acceleration

Vibration can be in terms of displacement, velocity, and acceleration. The easiest measurement to understand is that of displacement, or the magnitude of motion of the body being studied. Where the rate of motion, (frequency of vibration) is low enough, the displacement can be measured directly with a dial-gage micrometer. When the motion of the body is great enough, its displacement can be measured with a common scale.

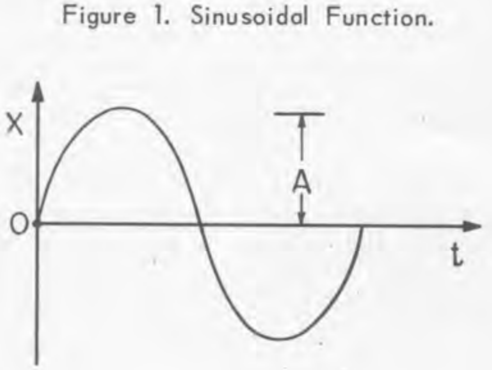
In its simplest case, the displacement may be considered as simple harmonic motion, that is, a sinusoidal function having the form

$$x = A \sin \omega t \qquad (1)$$

where A is a constant, ω is 2π times the frequency, and t is the time, as shown in Fig. 1. The maximum peak-to-peak displacement (the quantity indicated by a dial gage) is 2A, and the r-m-s[1] displacement is $A/\sqrt{2}$ (=.707A).

[1]root-mean-square

Figure 1. Sinusoidal Function.



The average (full-wave rectified average) value of the displacement is $2A/\pi$ (=.636A) while the "average double amplitude" (a term occasionally encountered) would be $4A/\pi$ (=1.272A). Displacement measurements are significant when deformation and bending of structures are studied.

In many other practical problems, however, displacement is not the important property of the vibration. A vibrating mechanical part will radiate sound in much the same way as does a loudspeaker. In general the velocities of the radiating part (which corresponds to the cone of the loudspeaker) and the air next to it will be the same, and, if the distance from the front of the part to the back is large compared to one-half of the wavelength of sound in air, the actual sound pressure in air will be proportional to the velocity of the vibration. The sound energy radiated by the vibrating surface is the product of the velocity squared and the resistive component of the air load. Under these conditions, particularly where noise is important, it is the velocity of the vibrating part and not its displacement which is of greatest importance.

Velocity is the time rate of change of displacement, or the first derivative of displacement with respect to time, so that for the sinusoidal vibration in equation (1) the velocity is

$$v = \frac{dx}{dt} = \omega A \cos \omega t \qquad (2)$$

Thus the velocity is proportional not only to the displacement but also to the frequency of the vibration.

In many cases of mechanical vibration, and particularly where mechanical failure is a consideration, the actual forces set up in the vibrating parts are important factors. Newton's laws of motion state that the acceleration of a given mass is proportional to the applied force, and that this force produces a resulting reacting force which is equal but opposite in direction. Members of a vibrating structure, therefore, exert forces on the total structure that are a function of the masses and the accelerations of the vibrating members.

Acceleration measurements are important where vibrations are sufficiently severe to cause actual mechanical failure. Acceleration is the second derivative of the displacement with respect to time or the first derivative of velocity with respect to time.

$$a = \frac{dv}{dt} = \frac{d^2x}{dt^2} = -\omega^2 A \sin \omega t \qquad (3)$$

The acceleration, therefore, is proportional to the displacement and to the square of the frequency.

There is another use for acceleration measurements. The analogy cited above concerning the loudspeaker covers the usual case where the cone or baffle is large compared to the wavelength of the sound involved. In most machines this relationship does not hold, since relatively small parts are vibrating at relatively low frequencies. This may be compared to a small loudspeaker without a baffle. At low frequencies the air may be "pumped" back and forth from one side of the cone to the other with a very high velocity but without building up much of a pressure or radiating much sound energy, because of the very low air load, which has a reactive mechanical impedance. Under these conditions the acceleration measurement provides a better measure of the amount of noise radiated than does a velocity measurement.

SUMMARY

Displacement measurements are used only in instances where the actual amplitude of motion of the parts is important. This would include those cases where the dynamic loading due to the operating machinery in a factory may cause unsafe deflections in flooring and walls or where large amplitude of motion might actually cause parts to strike together, thus causing damage or serious rattle. The deflections observed at the center of a wall panel or a beam, for example, can give useful information about the stresses acting in these members. The displacement is not directly a measure of surface strain of the member but is rather an integrated indication of the strain. The strain measured by the usual strain gage is a minute elongation or compression of material between points an inch or so apart; in contrast, the displacement measurement referred to above is the bending of material over a distance of several feet.

Velocity measurements are generally used in noise problems where the radiating surfaces are comparatively large with respect to the wavelength of the sound.

Acceleration measurements are the most practical where actual mechanical failure of the parts involved is of importance, and in many noise problems, particularly those involving small machinery. A general-purpose vibration meter, therefore, must be able to measure all three vibration characteristics.

NON-SINUSOIDAL VIBRATIONS

The above equations, (1), (2), and (3), represent only sinusoidal vibrations, but, as in the case of the other complex waves, complex periodic vibrations can also be represented as a Fourier series of sinusoidal vibrations. These simple equations may, therefore, be expanded to include as many terms as desirable in order to express any particular type of vibration. It will be noted that, since velocity is proportional to frequency, and acceleration is proportional to the square of the frequency, the higher frequency components in a vibration are progressively more important in velocity and acceleration measurements than in displacement readings.

CHAPTER III

DESCRIPTION OF GENERAL RADIO VIBRATION MEASURING INSTRUMENTS

Complete Catalog Specifications of all General Radio Company instruments described on the following pages are listed in Appendix II.

TYPE 761-A VIBRATION METER

The Type 761-A Vibration Meter fills the need for an instrument that can be used for measurements of low-frequency vibrations, or where a large number of accurate observations must be made with a maximum degree of convenience. It is mounted in a conveniently carried case, operates from an internal battery, and is simple and convenient to use. This vibration meter takes full advantage of the maximum frequency range of the piezo-electric type of pickup, which extends smoothly from 2 to 1000 cycles per second. The meter is calibrated directly in terms of the r-m-s displacement, velocity, and acceleration and in-

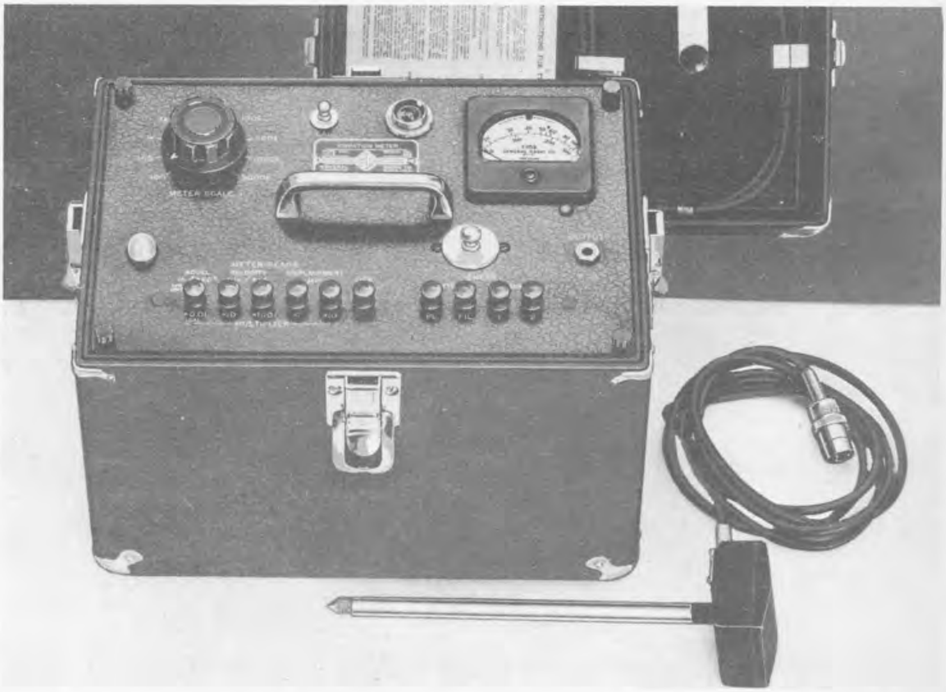


Figure 2. The Type 761-A Vibration Meter covers the frequency range from 2 to 1000 cycles per second (120 to 60,000 rpm).

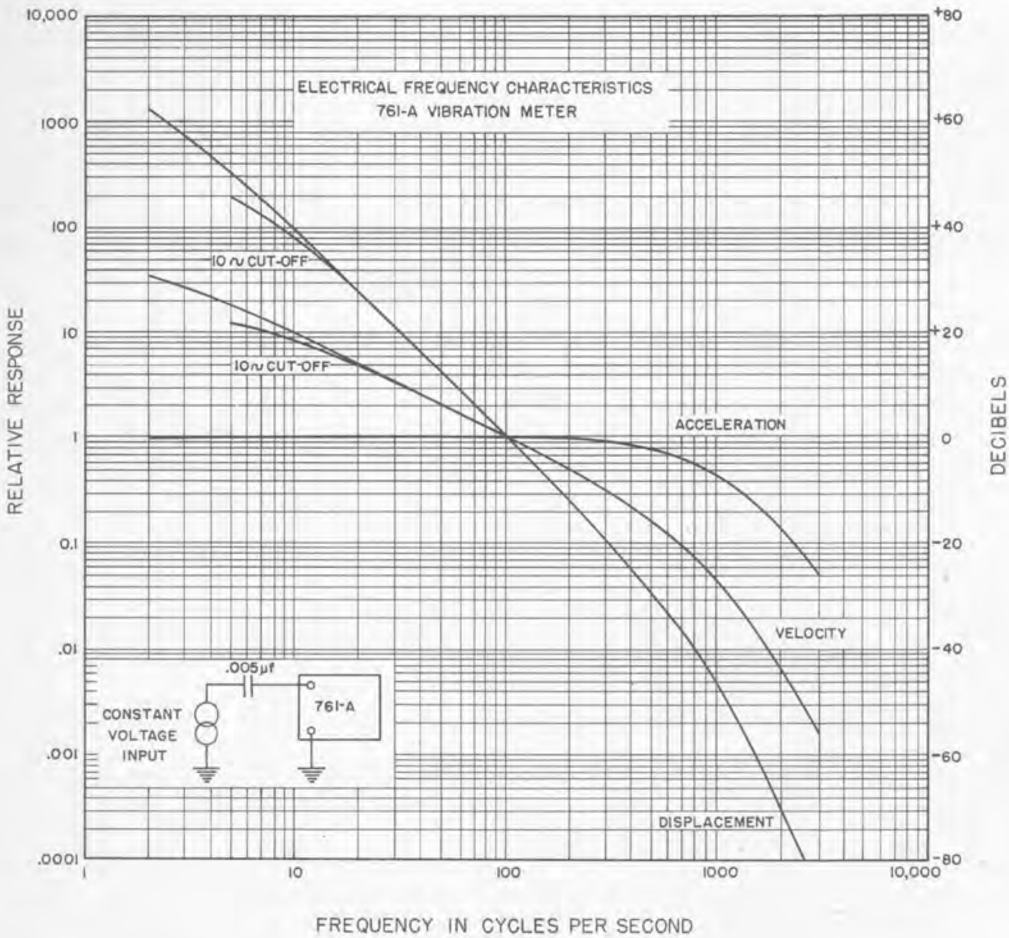


Figure 3. Electrical frequency response of the Type 761-A Vibration Meter showing effects of integrating circuit.

dicates these, respectively, in micro-inches, micro-inches per second, and inches per second per second.[2]

Since the vibration pickup used with this meter is of the acceleration[3] type, two stages of electrical integration are necessary to provide the various types of response. The integrating circuits are built in as part of the amplifier. This allows more freedom of choice in the design and better performance is possible than with the control box attachment, used with the sound-level meter, which is described in a following paragraph.

[2]The Type 761-A Vibration Meter is completely described in "A General-Purpose Vibration Meter" by H. H. Scott, Journal of the Acoustical Society of America, Vol. XIII, No. 1, pp. 46-50, July, 1941. A brief description is also included in the General Radio EXPERIMENTER, Vol. XVI, No. 1, pp. 1-8, June, 1941.

Figure 3 shows the electrical frequency characteristics of the vibration meter, excluding the pickup. Figure 4 shows the overall characteristics in terms of response for a constant-displacement vibration as a function of frequency. The peak in response above 1000 cycles is caused by the natural resonance in the pickup. It will be noted that the response is useful for direct reading purposes to about 1200 cycles per second, but can be used for relative indications up to 2000 cycles per second. These curves show graphically how the integration process attenuates the higher frequencies with respect to the lower frequencies.

[3]In this type of pickup the crystal is deflected by its own inertia when the pickup is subjected to vibration. The voltage generated is proportional to the actual force exerted on the crystal, which is proportional to the acceleration.

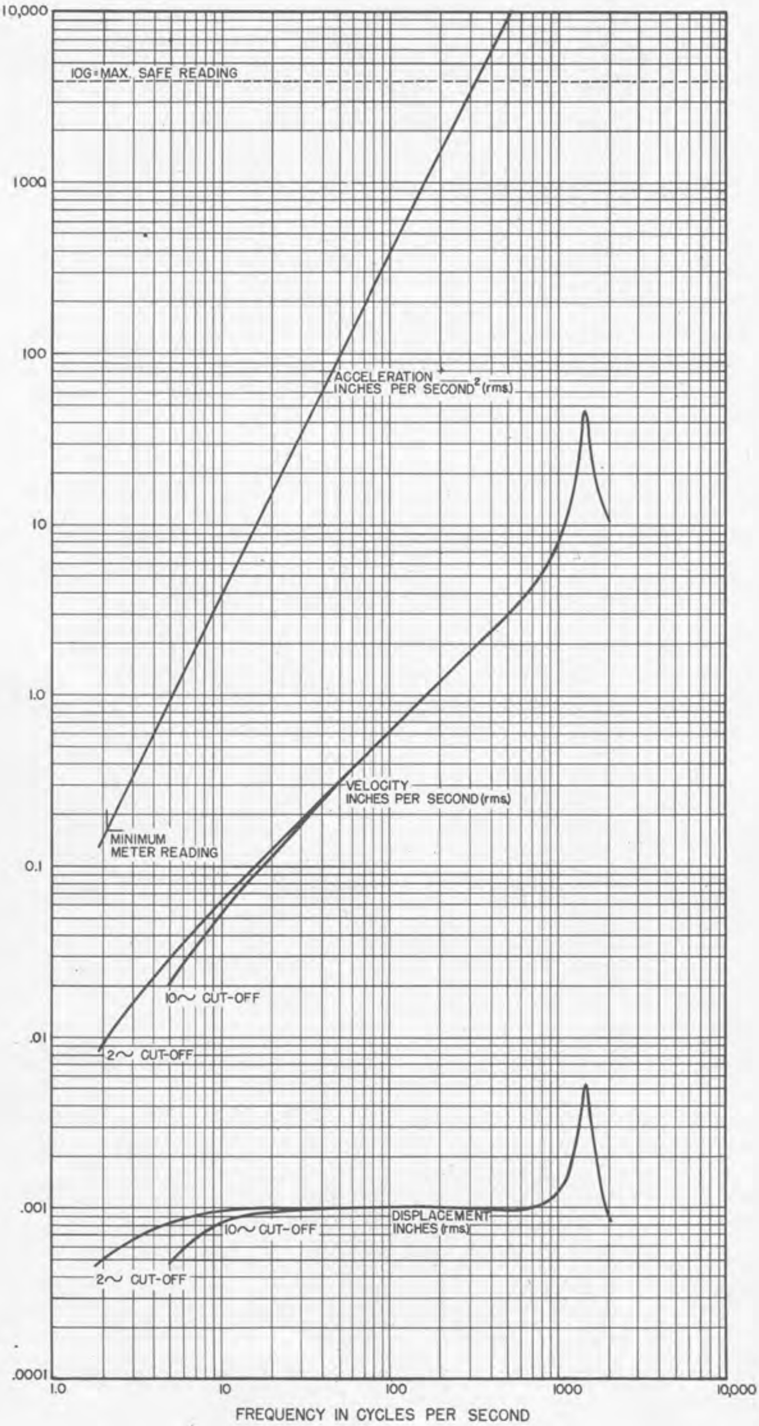


Figure 4. Readings of the Type 761-A Vibration Meter for a constant displacement of 0.001 inch (rms) as a function of frequency.

Figure 5. Oscillograms illustrating the operation of the integrating circuits in the vibration meter. In (a) a square wave is shown as transmitted by the amplifier when set for acceleration measurements; (b) shows the wave after one stage of electrical integration for velocity measurements; and (c) shows the result of two stages of integration as used for displacement measurements.[4]

Figure 5 shows the effect of the electrical integration on a particular waveform. The square waveform of Figure 5a has strong harmonics. After two steps of integration the result in Figure 5c is approaching sinusoidal waveform.[4]

VIBRATION PICKUP WITH THE SOUND-LEVEL METER

Vibration measurements can be made with a sound-level meter when a pickup, which responds to mechanical vibrations, is substituted for the

[4]The waveforms shown in Figure 5 may be represented by the following Fourier series:

$$(a)\quad a = -\omega_1^2 A \sin \omega_1 t - \frac{\omega_1^2 A}{3} \sin 3\omega_1 t - \frac{\omega_1^2 A}{5} \sin 5\omega_1 t - \cdots$$

$$(b)\quad v = \int a\,dt = \omega_1 A \cos \omega_1 t + \frac{\omega_1 A}{3^2} \cos 3\omega_1 t + \frac{\omega_1 A}{5^2} \cos 5\omega_1 t + \cdots$$

$$(c)\quad x = \int v\,dt = \int\int a\,dt = A \sin \omega_1 t + \frac{A}{3^3} \sin 3\omega_1 t + \frac{A}{5^3} \sin 5\omega_1 t + \cdots$$

Note that for this particular waveform, the acceleration equation gives 33% third harmonic, and the displacement one gives only 3.7%.

The Type 759-P35 Vibration Pickup and Type 759-P36 Control Box connected to the Type 1551-A Sound-Level Meter in place of the microphone.

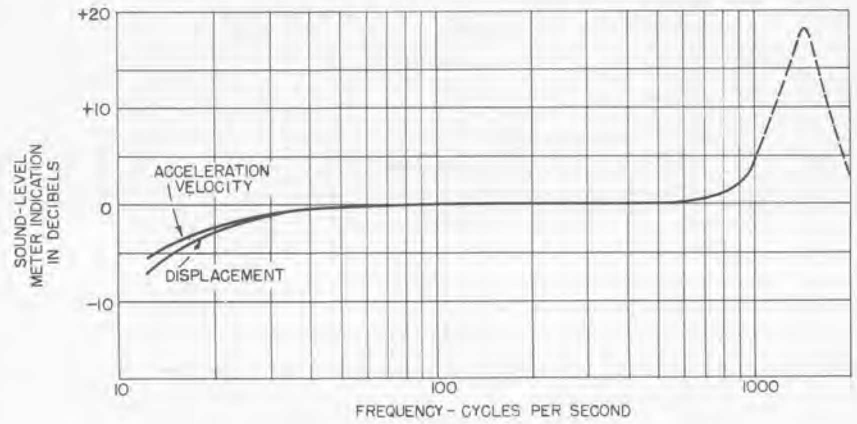


Figure 7. Over-all frequency response characteristic of the vibration pickup, control box, and sound-level meter for constant applied acceleration, velocity, and displacement, respectively.

microphone. With the Type 1551-A Sound-Level Meter, the Type 759-P35 Vibration Pickup and the Type 759-P36 Control Box are used. The pickup itself is of the inertia-operated piezoelectric type,[3] which is also used with the Type 761-A Vibration Meter. The control box, which connects between the meter and the pickup, provides electrical integrating circuits. The integrating circuits allow the conversion of this response for reading velocity or displacement. This combination of pickup, control box, and sound-level meter provides a convenient and inexpensive way for owners of sound-level meters to make vibration measurements within the audio-frequency range. However, it should be remembered that the sound-level meter circuits were intended only to respond down to 20 cycles, and consequently this combination is not suitable for measuring lower-frequency vibrations. The Type 761-A Vibration Meter must be used where low frequencies are important.

Also, the sound-level meter reads in terms of decibels, which must be converted to vibration amplitude, velocity, or acceleration. A calibration chart is provided with each control box giving the proper conversion factors for that pickup and control box when used with a particular sound-level meter. By means of these data plus the decibel table in Appendix I (also supplied in the instruction book for the pickup and control box), the readings may be converted readily to inches, inches per second, or inches per second per second.

ANALYZERS

The vibration meter measures the displacement, velocity, or acceleration of a vibration in terms of the r-m-s value of the waveform. Unless the waveform is substantially sinusoidal, however, the vibration meter by itself gives little information about the frequencies of the individual vibration components.[5] An analyzer, therefore, is desirable and in many cases a necessity. As with noise, the analysis of vibration provides clues to the sources of the various components and information necessary in the suppression of the vibration.

Vibration, like noise, may be classified into two types—pitched, which consists mainly of harmonics or subharmonics of a fundamental frequency, all of which will vary in frequency by the same percentage that the machine speed varies; and unpitched, which is caused by shock excitation and occurs over bands of frequencies.

A number of analyzers are available which can be used with the Vibration Meter or with the Sound-Level Meter, Control Box and Vibration Pickup combination to extend the range of usefulness of these instruments. These analyzers vary in complexity and ease of operation. The relative usefulness of each analyzer depends on the vibration problem to be solved as will become evident

[5]For *sinusoidal* vibrations, the frequency can be calculated from readings of displacement and velocity. As shown in Equations (1) and (2), the frequency will be: $f=v/2\pi x$ Where the displacement (x) is in inches and the velocity (v) is in inches per sec.

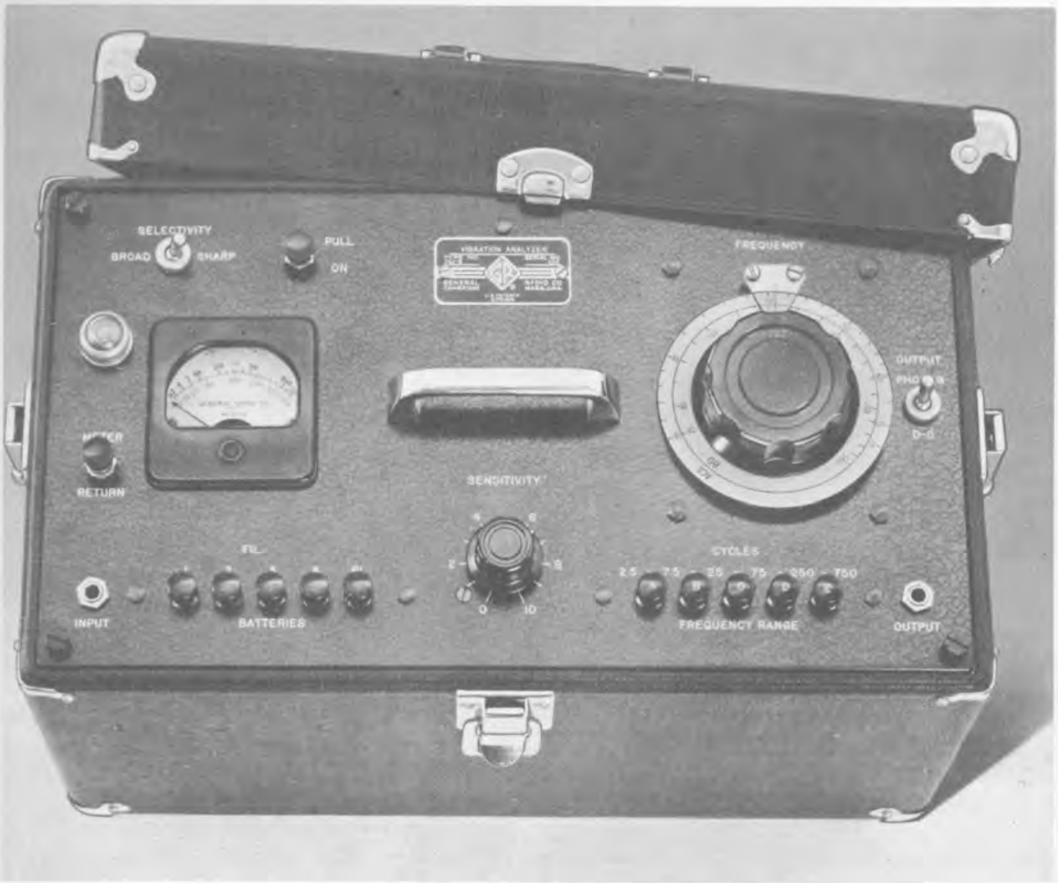
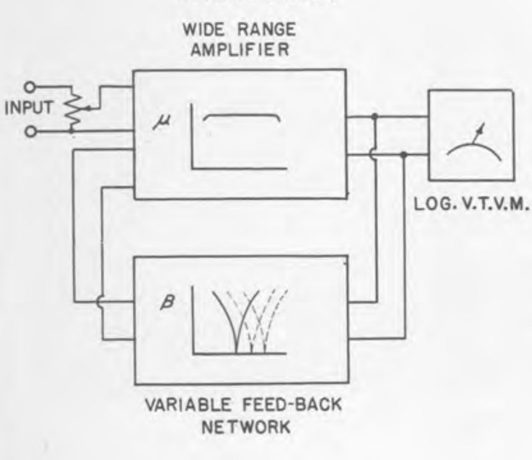


Figure 8. The Type 762-B Vibration Analyzer.

Figure 9. Functional block diagram showing the operation of the Type 762-B Sound Analyzer. It consists of a high-gain amplifier and a frequency-selective feedback network, so designed that the feedback is degenerative at all frequencies except that to which the network is tuned.



as the instruments are described. One of the analyzers (the Type 762-B Vibration Analyzer) was designed specifically for use with the Type 761-A Vibration Meter to make vibration analysis a convenient process.

TYPE 762-B VIBRATION ANALYZER

The Type 762-B Vibration Analyzer is a continuous-spectrum instrument. It is small, portable, lightweight, and battery operated. It includes a three-stage direct-coupled amplifier which is made selective by means of a tunable null circuit in a negative-feedback loop. Operation is simple and easy, and the entire frequency range of the instrument can be conveniently scanned. Any one of five push-button-controlled ranges can be selected at will, and the frequency is read from a single dial, which can be rotated continuously in either direction. The circuit elements consist only of resistors and capacitors, and the case is electrostatically shielded, so that this instrument is unaffected by ordinary electromagnetic and electrostatic fields.

The Type 762-B Vibration Analyzer covers the frequency range from 2.5 to 750 cycles per

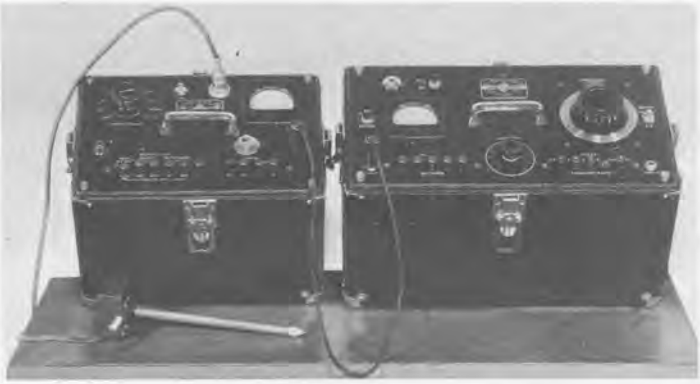
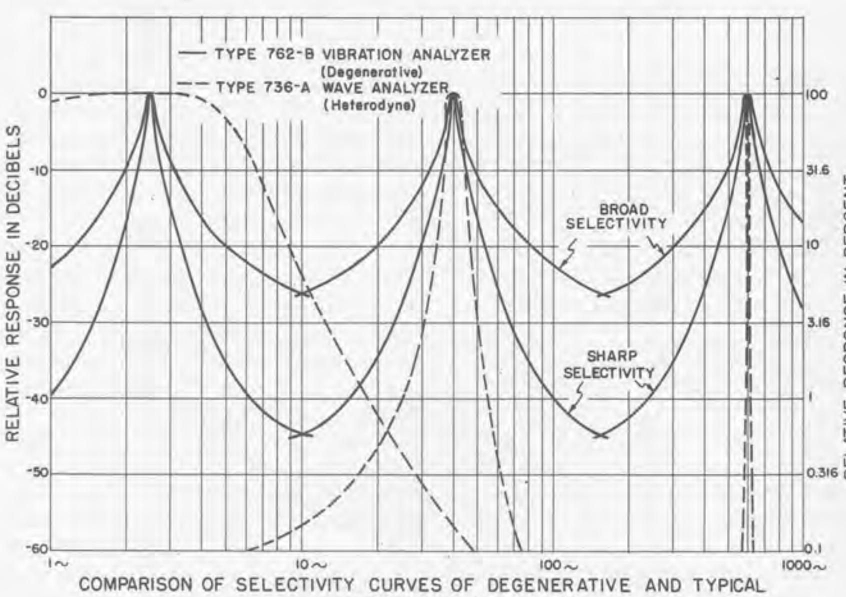


Figure 10. The Type 762-B Vibration Analyzer was designed particularly for use with the Type 761-A Vibration Meter.

second (150 to 45,000 rpm). The meter scale is calibrated in linear units for reading displacement, velocity, and acceleration directly in terms of micro-inches, micro-inches per second, and inches per second per second, respectively. Thus, in combination with the Type 761-A Vibration Meter, this analyzer provides a convenient means for measuring not only the overall vibration level but also the relative amplitudes of the component frequencies.

The selectivity characteristics are shown in Figure 11. It will be noted that the selectivity curve maintains a constant shape in terms of percentage of the resonant frequency over the entire range. The negative feedback circuit, so far as is known at the present time, provides the most satisfactory means for obtaining high selectivity at sub-audible frequencies.

Two band widths are provided, selection being made by means of a panel switch. The BROAD SELECTIVITY position is extremely helpful in locating components quickly in a fast sweep over the spectrum, the final determination of frequency and amplitude being made with the SELECTIVITY switch in the SHARP position. It is also used in making the final determination of frequency and amplitude when the frequency of the component under measurement is drifting rapidly or is fluctuating about a mean frequency by several percent.



COMPARISON OF SELECTIVITY CURVES OF DEGENERATIVE AND TYPICAL HETERODYNE ANALYZERS

Figure 11. Selectivity characteristics of the Type 762-B Vibration Analyzer as compared with a typical (Type 736-A) heterodyne type of wave analyzer. Of utmost importance is the selectivity curve of the vibration analyzer which maintains a satisfactory width and shape at both low and high vibration frequencies.

Figure 12.
The Type 760-B
Sound Analyzer.

OTHER USEFUL ANALYZERS

TYPE 760-B SOUND ANALYZER

The Type 760-B Sound Analyzer is similar to the Type 762-B Vibration Analyzer. The general design features of the two analyzers are alike. The frequency range of the Sound Analyzer is 25 to 7500 cycles per second, and, since the analyzer was designed to operate with the Sound-Level Meter, its meter has both a db scale and a percent scale. This instrument lacks the broad-sharp selectivity feature of the low frequency model, but it is extremely useful for frequency analysis of vibrations above 25 cycles per second.

Figure 13.
The Type 736-A Wave Analyzer.

TYPE 736-A WAVE ANALYZER

The Type 736-A is an a-c operated, heterodyne-type, vacuum-tube voltmeter. The intermediate-frequency amplifier includes a highly selective quartz-crystal filter. The use of a heterodyne method makes it possible to vary the response frequency while using a fixed frequency filter. This is a fairly complex instrument, better suited to laboratory use than to portable or field use. However, it can provide a great deal of information about the frequency spectrum. It operates over a very wide range of input voltages (300 microvolts to 300 volts full scale). It has a fixed band with a four-cycle flat top and high rejection outside the pass band. For vibration measurements above approximately 200 cycles per second the fixed band width is narrower than the band width of the Type 762-B Analyzer so that unless components in the upper spectrum are stable in frequency this analyzer becomes difficult to use. At low frequencies, as is indicated in Figure 11, the fixed band width of heterodyne type analyzer is too wide to be usable. For these reasons the Type 762-B Vibration Analyzer is much better suited for vibration measurements even though its rejection outside the pass band does not approach that of the Type 736-A Wave Analyzer.

Figure 14.
The Type 1550-A Octave-Band Noise Analyzer.

TYPE 1550-A OCTAVE-BAND ANALYZER

This analyzer was designed to make possible the simple and rapid analysis of noises having complex spectra. It operates directly from the output of the Vibration Meter or Sound-Level Meter and is more convenient to use than the narrow-band analyzers. Although it does not operate down to the low frequencies desired for many vibration measurements, it should prove useful for those vibration measurements that are being made in connection with noise reduction problems. It can be used when detailed knowledge of the individual frequency components is not required.

This analyzer consists of a set of eight band-pass filters, one octave wide, with selection by means of a rotary switch, followed by an attenuator and an amplifier, which drives both an indicating meter and a monitoring output. These bands are 20 c to 75 c, 75 c to 150 c, 150 c to 300 c, 300 c to 600 c, 600 c to 1200 c, 1200 c to 2400 c, 2400 c to 4800 c and 4800 c to 10,000 c. Only the first five bands, however, are within the useful range of the Type 761-A Vibration Meter.

The power is supplied by means of a self-contained battery block, and an a-c power pack that fits the battery compartment is available separately.

For convenience and flexibility, circuits and panel jacks are arranged so that the filter section or the amplifier can be used alone.

ADDITIONAL EQUIPMENT THAT CAN BE USEFUL IN VIBRATION MEASUREMENT:

STROBOSCOPES

Although it cannot measure directly the magnitude of vibration in rotating or moving parts, the stroboscope is valuable in many vibration studies because it permits rotating or reciprocating objects to be viewed intermittently and produces the optical effect of slowing down or stop-

Figure 15. The Type 631-BL Strobotac.®

Figure 16. The Type 648-A Strobolux® shown with the Type 631-BL Strobotac.

Figure 17. The Type 1532-B Strobolume.®

ping motion. For instance an electric fan revolving at 1800 rpm will apparently be standing still if viewed under a light that flashes uniformly 1800 times per minute. At 1799 flashes per minute, the fan will appear to revolve at 1 rpm, and at 1801 flashes per minute, it will rotate backward at 1 rpm. Because the eye retains images for an appreciable fraction of a second, no flicker is seen except at very low speeds. The apparent slow motion is an exact replica of the original higher-speed motion, so that the motion of a high speed machine can be analyzed with the stroboscope under normal operating conditions. This type of instrument can be used to measure the critical speeds where vibrations occur in all types of rotating or reciprocating machinery. Displacements in vibrating parts can often be measured accurately with the aid of a microscope if a fine reference line is scribed on the part. We have used this technique to confirm the calibration of an electrodynamic Vibration Calibrator and automotive engineers have used it in measuring crankshaft whip and vibration.[6]

The high speed performance of fans and propellers and other rotating devices can be studied while in operation, by means of the slow motion effect of the stroboscope, and sources of vibration and noise due to misadjustments, misalignment, or wear can readily be detected.

TYPE 631-BL STROBOTAC® (STROBOSCOPIC TACHOMETER)

The Strobotac is a small portable stroboscope calibrated to read speed directly in revolutions per minute. The light source is a neon strobotron lamp mounted in a parabolic reflector. The frequency of an internal electronic pulse generator determines the flashing speed, which can be adjusted by means of a direct reading dial. Normal range is from 600 rpm to 14400 rpm (10 cps to 240 cps) with an additional low range of 60 rpm to 1440 rpm (1 cps to 24 cps). Speeds above and below the normal range can be measured by using flashing rates that are simple multiples or submultiples of the speed to be measured. As the flashing rate of the Strobotac is decreased below 600 per minute, the flicker becomes pronounced due to the low average level of illumination and to the inability of the human eye to retain successive images long enough to give the illusion of continuous motion. The illumination level can be increased by the use of either the Type 648-A Strobolux or the Type 1532-B Strobolume.

TYPE 648-A STROBOLUX®

The Strobolux is an auxiliary white light source designed for use with the Strobotac where greater light intensity is required or where areas to be illuminated are larger than the Strobotac can cover. The Strobolux uses the Strobotac as the triggering source and furnishes a white light about 100 times as powerful as the Strobotac. The Strobolux is made up of a power supply and lamp (filled with rare gas) capable of producing the brilliant light flashes at rates up to 6000 per minute.

TYPE 1532-B STROBOLUME

The Strobolume produces brilliant, high intensity, white flashes continuously at rates up to 60 per minute or for short periods at rates up to 1200 per minute. It will also produce flashes of shorter duration (about 1/20th as much light) at rates up to 3000 per minute continuously. The Strobolume is designed to be flashed from an external source such as the Type 631-BL Strobotac. Its intense white flash is especially well suited for studying the motions or vibrations of machines operating at relatively low speeds where the light from the Strobotac is inadequate.

light ? vs 631-BL

[6] M. M. Roensch, "Measurements of Crankshaft Whip and Vibration", *Instruments*, April,, 1933.

CHAPTER IV

ADDITIONAL EQUIPMENT OF OTHER MANUFACTURE

In addition to extended information gained by use of analyzers at the output of the Vibration Meter, the range of usefulness of the instrument can be expanded by the use of a number of other pieces of associated equipment. In general the Type 761-A Vibration Meter performs as an accurately calibrated preamplifier, amplifier, and indicating meter for the accelerometer (Type 761-P1 Piezo-Electric Vibration Pickup). It also provides a low-distortion, hum-free output for the operation of such auxiliary equipment as a cathode-ray oscillograph, magnetic tape recorder, or recording oscillograph.

CATHODE-RAY OSCILLOGRAPH

A cathode-ray oscillograph is standard equipment in almost any laboratory. It is a useful means for observing the waveform of a vibration signal from the vibration meter. It can be used to measure the peak amplitude of a wave, and after some experience the observer can, by adjusting the sweep frequency, tell something about frequency components by looking at the waveform. In addition the cathode-ray oscillograph makes possible the study of the instantaneous values of a vibratory motion. In contrast with the vibration analyzer and other wave analyzers that present information in terms of frequency, the cathode-ray oscillograph, and recording galvanometers described below, present information as a function of time. This time representation is often of great assistance in the solution of vibration problems. The cathode-ray oscillograph, because it presents information instantly and continuously, and because its frequency response is not a limiting factor, is useful in the study of any vibration waveform.

For vibration measurements a cathode-ray oscillograph with slow sweep rates, a long persistence screen and a d-c amplifier is preferable. Many oscillographs have provision for the addition of a camera which makes possible a permanent record of the vibration wave shape being studied.

MAGNETIC TAPE RECORDER

The magnetic tape recorder has become a very useful tool for the research and development engineer. As a tool for vibration measurements, for example, it is being used to perform the following functions:

1. The preservation of a vibration signal for later analysis and display or for comparison with vibration measurements after adjustments or changes have been made in the equipment or machine being measured.

2. The storage of a sample, low frequency vibration signal which can be played back at higher tape speeds to make analysis possible with conventional audio-frequency analyzers.

3. The storage of shock- or impact-type vibration signals for reverse playback to determine peak amplitudes. (Conventional meters can then be used to follow the decay slope in reverse even though the response time is much too slow to indicate peak values when the signal is played back in the forward or correct direction.)

4. Recorders using a special FM carrier technique which will record with flat response from dc to 3000 cps have been used for low frequency vibrations and seismic exploration work.[7]

---

[7]Kenneth P. Booth, "Tape Recording for Telemetering and Data Analysis", TELETECH, May & June, 1952.

The recorder selected must be a high quality instrument if accurate analyses are desired. This means a flat frequency characteristic, low hum and noise level, low non-linear distortion, wide dynamic range, and constant speed.

RECORDING GALVANOMETER

The recording galvanometer is a tool that is widely used in vibration measurement and analysis. It is very useful in applications where the vibration to be measured is transient in nature, including the cases where the vibration is essentially at a constant frequency but its amplitude varies widely with time.

Many models are available and most of them can be used to record the waveforms appearing at the output jack of the Type 761-A Vibration Meter.

Direct-writing types using a pen motor may write with ink on paper, with special styli on heat-sensitive paper or voltage-sensitive paper, or with a pointed stylus on waxed paper. The pen motors usually have relatively low resonant frequencies and require d-c amplifiers to be used with the vibration meter. Most companies that manufacture the pen motor manufacture the corresponding d-c amplifier. In some cases compensation is added to extend the flat response range of the pen motor. Pen motors with compensating amplifiers are useful from d-c up to about 100 cycles per second.

A more versatile recorder is the type in which the galvanometer moves a tiny mirror which reflects a light beam onto a photographic paper or film. Here sensitivity and resonant frequency can be increased, because the mirror can be tiny and very light, and the light path from mirror to recording surface can easily be made relatively long. Flexibility is increased, because galvanometer units varying widely in sensitivity and frequency range can be readily interchanged. Many of these galvanometers can be operated from the output of the vibration meter with the use of a resistive pad and no extra amplification. Units with resonant frequencies as high as 3000 cycles are available. Since the record is produced on a photographic film or paper and is not immediately available, this type of recording galvanometer is not so convenient to use as the direct writing type. To reduce the time lag between test and viewing or interpretation of data at least two companies[5] have recently announced compact photo-record processors for paper oscillograms and other rolled paper photo-records. The units require no dark room for operation and can be used at the testing site without connection to external source of water.

---

[5]Consolidated Type 23-109, Consolidated Engineering Corporation, 300 North Sierra Madre Villa, Pasadena, 15, California.

General Electric Catalogue No. 9894820—General Electric Company, Schenectady, New York.

CHAPTER V

APPLICATIONS FOR GENERAL RADIO VIBRATION MEASURING EQUIPMENT

All designers of airplanes, ships, and other expensive or elaborate structures, particularly where vibration may be dangerous, carefully calculate the vibratory conditions as a part of the design work. Such calculations generally involve assumptions which cannot always be rigidly justified, and measurements are usually necessary on the completed structure to check the calculations and make minor readjustments.

With small machinery it is sometimes more economical to build a sample and measure the vibration than to spend too much time on laborious calculations. The vibration meter, therefore, is not a substitute for thorough theoretical analyses, but should be used to supplement and check such analyses. In many cases its use will greatly simplify the calculations and reduce the number that are necessary.

Figure 18. The vibration meter and analyzer are used here to determine the amount of vibration absorbed by a new Gates tire. The tire is taking extreme punishment from a cleat on the large wheel, which is traveling so fast that the cleat cannot be seen.

The vibration meter is also an invaluable tool in checking finished equipment for vibration and, indirectly, for noise.[9] This last application allows noise tests to be carried on under unfavorable conditions of ambient noise level, after correlating noise meter and vibration tests on a few sample machines.

Engineers faced with the problem of dealing with vibration in some piece of equipment have often approached the solution, sometimes satisfactorily, by the wasteful procedure of "cut and try" or intuitive experiments. This procedure is not necessary or recommended and is often completely unsuccessful. Vibration measuring equipment and techniques are available which make possible the analysis and evaluation of any vibration problem. The analysis usually will provide the information necessary to solve the problem.

The General Radio Type 761-A Vibration Meter with the associated equipment described in Chapter IV and other equipment described here has been a very useful tool for many research and development engineers faced with a vibration problem. Noise levels from fans and large room air circulators have been reduced to acceptable levels by using information gained by vibration measurements on fan blades and circulator housings. Similar techniques have been used in the development of the increasingly popular room air-conditioners. Ball bearing manufacturers use the vibration meter as a tool to test assembled ball bearings as they come off the production line. Analysis of waveforms produced permits the operator to determine which component is responsible for a defective unit so corrective measures can be taken at the high speed automatic machines shaping or forming the part.

The vibration meter is widely used in the testing and evaluation of resilient mountings used for shock and vibration isolation. A manufacturer of rubber products uses the Type 761-A Vibration Meter and the Type 762-B Vibration Analyzer to aid in the development of products they are designing to have superior shock-absorbing qualities. For example, they use the equipment to measure the amount of vibration absorbed by their automobile tire (Fig. 18)[10] and to measure the shock absorbing qualities of special shock-absorbing power transmission belts (Fig. 19)[10] or power take-off wheels.

The engineering department of a company manufacturing Diesel engines uses the Type 761-

[9]Peterson, Arnold, P. G., and Beranek, Leo L., *Handbook of Noise Measurement*, General Radio Company, (see Section 6.9, "A Noise Problem").

[10]"Bumps Take a Beating," Research in Action section of *Gates Employees Progress News*, August, 1953, p. 9, The Gates Rubber Company, Denver, Colorado.

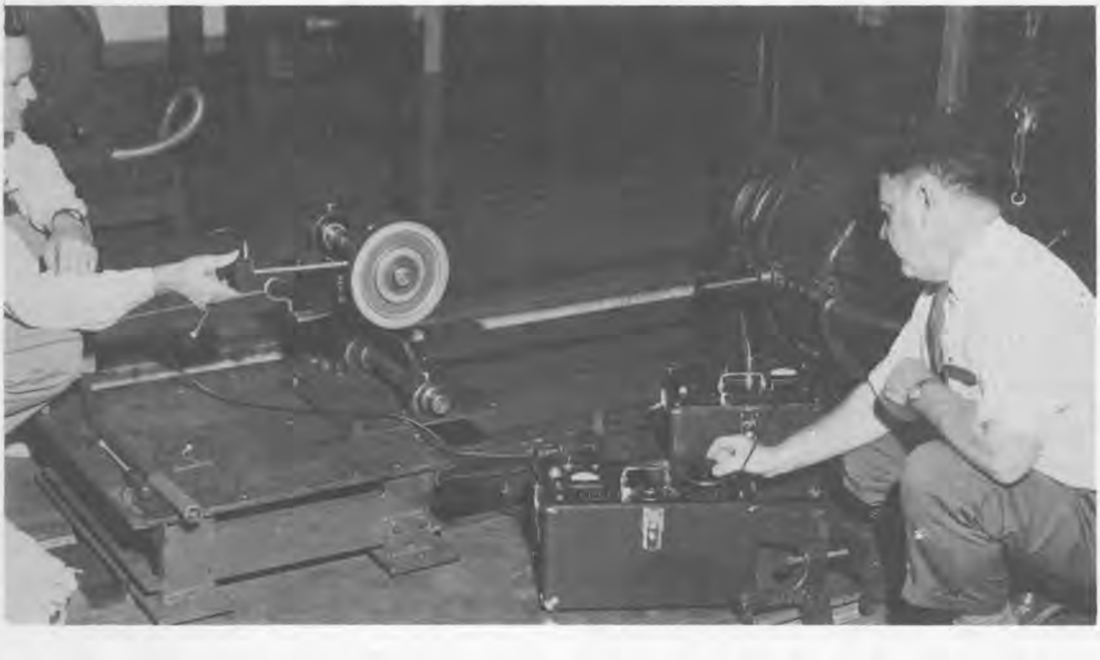


Figure 19. Shock-absorbing qualities of the Gates Super Rope are measured with the equipment shown here. Readings are taken at both the motor and the driven machine to determine how much vibration is absorbed by the belt.

A Vibration Meter and the Type 762-B Vibration Analyzer in a measuring system developed to measure, in the field, the torsional vibration characteristics of marine and stationary engine installations.[11] In these installations it is essential that no criticals (excessive torsional vibrations) occur within the operating range.

The examples listed above are cited to illustrate the wide range of activities in which the General Radio Vibration Measuring equipment has proved useful. Although the list is by no means complete, these examples indicate the versatility of the measuring instruments.

---

[11]White, Trescott S., "Taking the Mystery Out of Torsional Vibration", *Bulletin No. EM-B7*, Enterprise Engine and Machine Company, 18th and Florida Streets, San Francisco 10, California.

Figure 20. Trescott S. White, Engineer, Enterprise Engine and Machine Company, using vibration-measuring equipment to measure transverse motion of a large engine. The pickup shown here is replaced by a torsional pickup mounted on the engine shaft when torsional vibration is measured.

CHAPTER VI

HOW TO USE GENERAL RADIO VIBRATION MEASURING EQUIPMENT

TYPE 761-A VIBRATION METER

Operating Instructions

The instruction sheet fastened in the cover of the vibration meter outlines the actual operations involved in adjusting and reading the instrument. A knob marked METER SCALE provides, in effect, a multiplier for the indicating instrument. The red meter scale is used with the red positions of the knob and the black scale with the uncolored positions. The reading of the METER SCALE control in all cases represents the full-scale deflection of the meter, so that it is merely necessary to read the meter and locate the decimal point.

In addition, there is a row of five push buttons to select acceleration, velocity, and displacement response. For each of the latter two characteristics two buttons are provided. The normal buttons are those which provide a low-frequency limit of 2 cycles. The extra buttons, which are so marked, provide a low-frequency limit of 10 cycles, which however, allows an increase in sensitivity of the meter by a factor of 10:1. This is a great advantage for measuring low-amplitude vibrations such as occur, for instance, in clocks, speedometers, and other small mechanisms. Such vibrations seldom have any important components below 10 cycles. Below each button is engraved a multiplying factor (always a multiple of 10) which should be applied to all readings when that particular button is used.

Push buttons are also provided for checking the battery and the calibration.

How to read the Vibration Meter can be described most easily by using an example. Let us assume that you want to measure the displacement of a vibrating object and that after you have followed the instructions on MAKING VIBRATION MEASUREMENTS printed on the operating instruction sheet, fastened in the cover of the instrument, you have the following settings and reading:

1. the METER READS and MULTIPLIER button labeled "DISPLACEMENT" is depressed. μin. x 10
2. the METER SCALE switch is set at 10 K.
3. the panel meter reads 40 on the upper or black scale.

The indicated rms displacement is 4K x 10 μin. = 4000 x 10 μin. = 40,000 μin. = .040 in. If the vibration is sinusoidal:

the peak displacement is .040 x 1.414=.057 in.

the peak to peak displacement is .040 x 2.828 =.113 in.

Meter reading when vibration is non-sinusoidal:

The meter on the Type 761-A Vibration Meter is a special copper oxide rectifier type meter. The rectifiers are operated at low current density, so they are approaching square-law operation. The meter is calibrated to read the r-m-s value of a sine wave and will pass the test for root-mean-square addition specified in Appendix B of the *ASA American Standard for Sound-Level Meters for the Measurement of Noise and Other Sounds*, (Z24.3-1944). This does not mean that the meter indicates the true r-m-s value of all vibration waveforms. On complex waves the meter indicates a value that approaches the full-wave-rectified average (which we shall call average) rather than the r-m-s value of the wave. This meter indication closely approximates, too, an r-m-s indication for a number of common waveforms. For example: (a) on square waves, where peak, r-m-s, and average values are alike, the meter indicates true r-m-s, (b) on triangular waves the meter indication will be above r-m-s by something less than 3% and (c) on broad-band noise signals (white noise) the meter indication will be below r-m-s by approximately 10%.

On repetitive impulse-type waveforms such as may be encountered when measuring vibrations on punch presses or drop-hammers the meter on the Type 761-A Vibration Meter can indicate values that are below the r-m-s value of the wave by a factor of 3 or more. It is impossible to predict what the error in reading will be unless the wave-form of such a vibration is known. In general it is the peak value of such a vibration that is of interest so that, for impact-induced vibrations, the readings taken with the Type 761-A are useful for comparison purposes only.

However, much useful information can be obtained if the Type 761-A is used as a pre-amplifier for a peak-reading voltmeter, a cathode ray oscillograph, or a recording galvanometer. When one of these additional indicators is calibrated to read the peak values of displacement, velocity, or acceleration by means of the 60-cycle line calibration system in the Type 761-A the calibration procedure is as follows:

1. Connect the vibration meter to the 60-cycle line as when adjusting its calibration.

2. Connect the auxiliary indicator to the output terminals of the vibration meter.

3. Depress the button marked CALIBRATE 1 on the vibration meter. The panel meter of the vibration meter will read approximately 160 on the red or lower scale or approximately 50 on the black or upper scale.

4. A vacuum-tube voltmeter, such as the General Radio Type 1800-A or Type 1803-B, connected across the output terminals of the vibration meter will read approximately 2.5 volts. Since both the Type 1800-A and the Type 1803-B are peak reading voltmeters calibrated to read r-m-s on a sine wave signal we can relate this voltage reading to the peak value of the 60 cycle sinusoidal signal that is causing the reading. We can say that the 2.5 volt reading corresponds to a peak reading of 1.4 x 160=224 on the red scale and 1.4 x 50=70 on the black scale. Therefore, in this example, the auxiliary voltmeter reading should be multiplied by

$$\frac{224}{2.5} = 89.6$$

when the red scale of the vibration meter is used, and it should be multiplied by

$$\frac{70}{2.5} = 28$$ when the black scale is used. Once we have established these relations, we can use the vibration meter to measure the peak values of vibration quantities by reading the auxiliary voltmeter and applying the multiplying factors obtained as above in addition to those indicated by the METER SCALE switch and METER READS-MULTIPLIER buttons on the vibration meter.

When a cathode ray oscillograph or recording galvanometer is used as an auxiliary indicator, the calibration technique is much the same. The peak deflection caused by the known 60-cycle calibration signal can be compared directly with the meter reading of the Type 761-A.

When measurements on impulse- or impact-type vibrations are made, it is desirable to set the meter scale switch on the vibration meter so that the panel meter reads below mid-scale. Since the meter tends to read low on such waveforms, this setting will help to eliminate overloading or clipping in the output amplifier of the vibration meter.

Sensitivity of Vibration Meter

The Type 761-A Vibration Meter will measure, and read directly, r-m-s displacements as low as 16 micro-inches, velocities as low as 160 micro-inches per second, and accelerations as low as 0.160 inches per second.[12] The direct reading ranges of the Type 761-A are shown in charts of Figures 22, 23, 24 and are tabulated in Figure 25.

At frequencies above 25 cycles per second, sinusoidal displacements of 1 micro-inch and lower can be determined, if the frequency is known, by converting velocity readings to displacement values using the charts in Figure 21 or 24. For example, if the velocity is measured to be .001 inches/sec (1000 μinches/sec) and the frequency is known to be 200 cps, the displacement as read from the chart in Figure 21 would be 0.8 microinch.

Similarly, smaller displacements at higher frequencies can be determined from the acceleration measurements, but, unless the frequency is accurately known and the waveform a good sinusoid, this conversion is not reliable.

Maximum Readings of Vibration Meter

As indicated in Figures 22, 23, 24, and 25 the maximum values of displacement or velocity that should be applied to the pickup of the Type 761-A Vibration Meter vary with frequency, while between 2 cps and 1000 cps the maximum value of acceleration is essentially independent of frequency. In each case the maximum is that value which corresponds to an acceleration of 3900 inches per second per second or 10 times the acceleration due to gravity (10 g). Accelerations above 10g may damage the Rochelle salt crystal

[12]The displacement and velocity figures are for a low frequency cut-off at 10 cycles. These limits are multiplied by 10 when the full range down to 2 cycles is used.

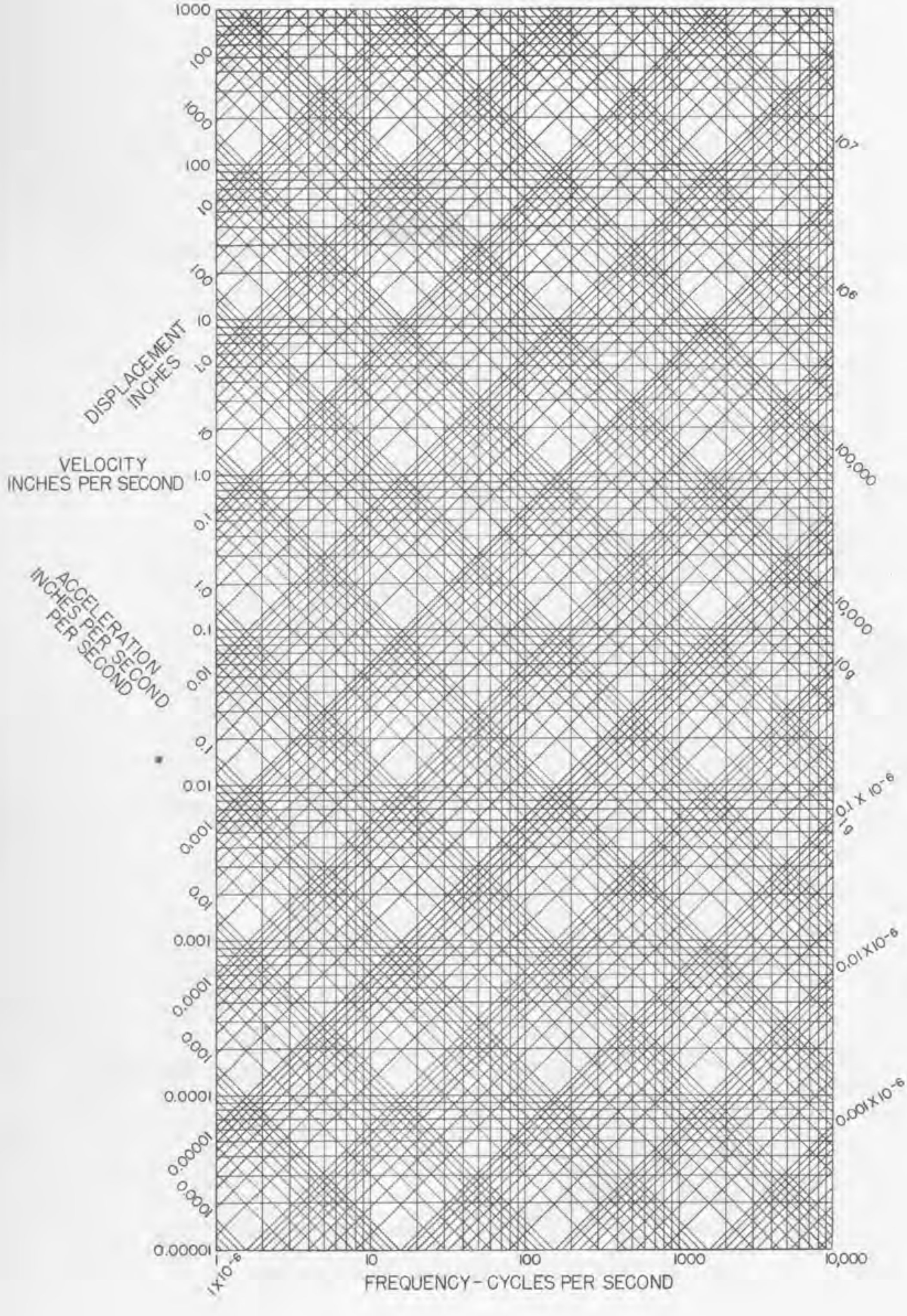


Figure 21. Conversion chart for vibration parameters.

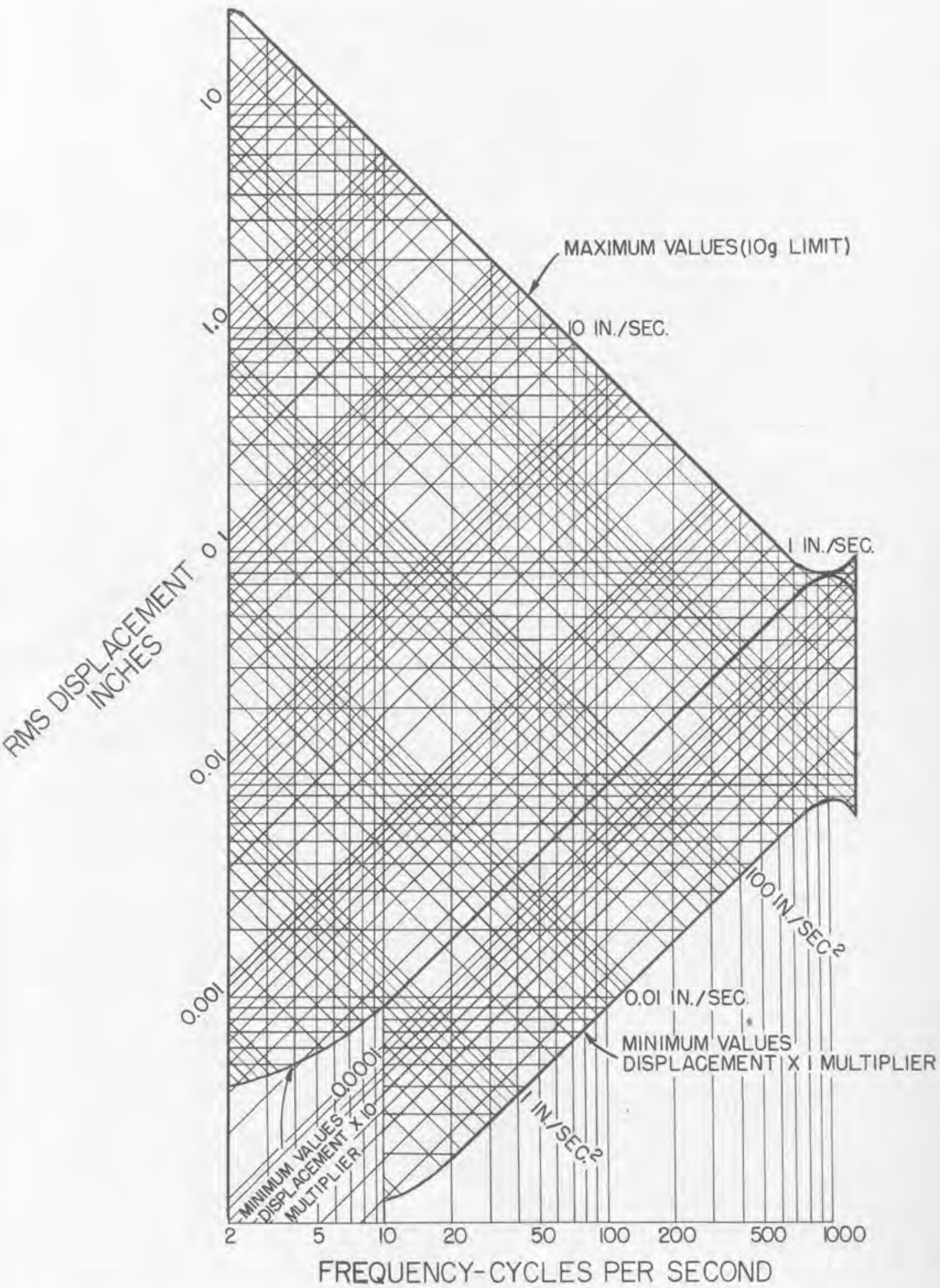


Figure 22. Chart showing the direct-reading displacement ranges of the Type 761-A Vibration Meter.

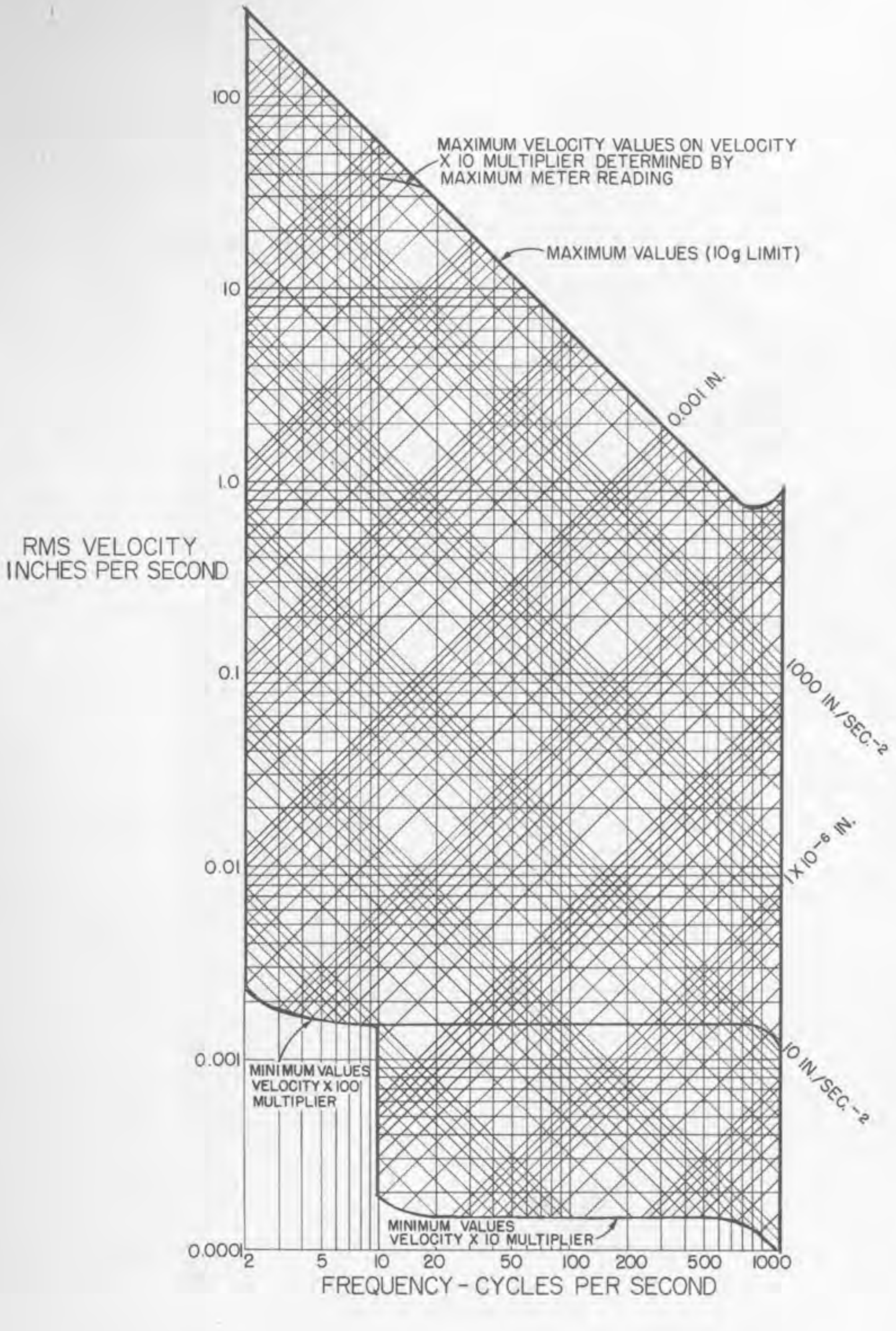


Figure 23. Direct-reading velocity ranges of the Type 761-A Vibration Meter.

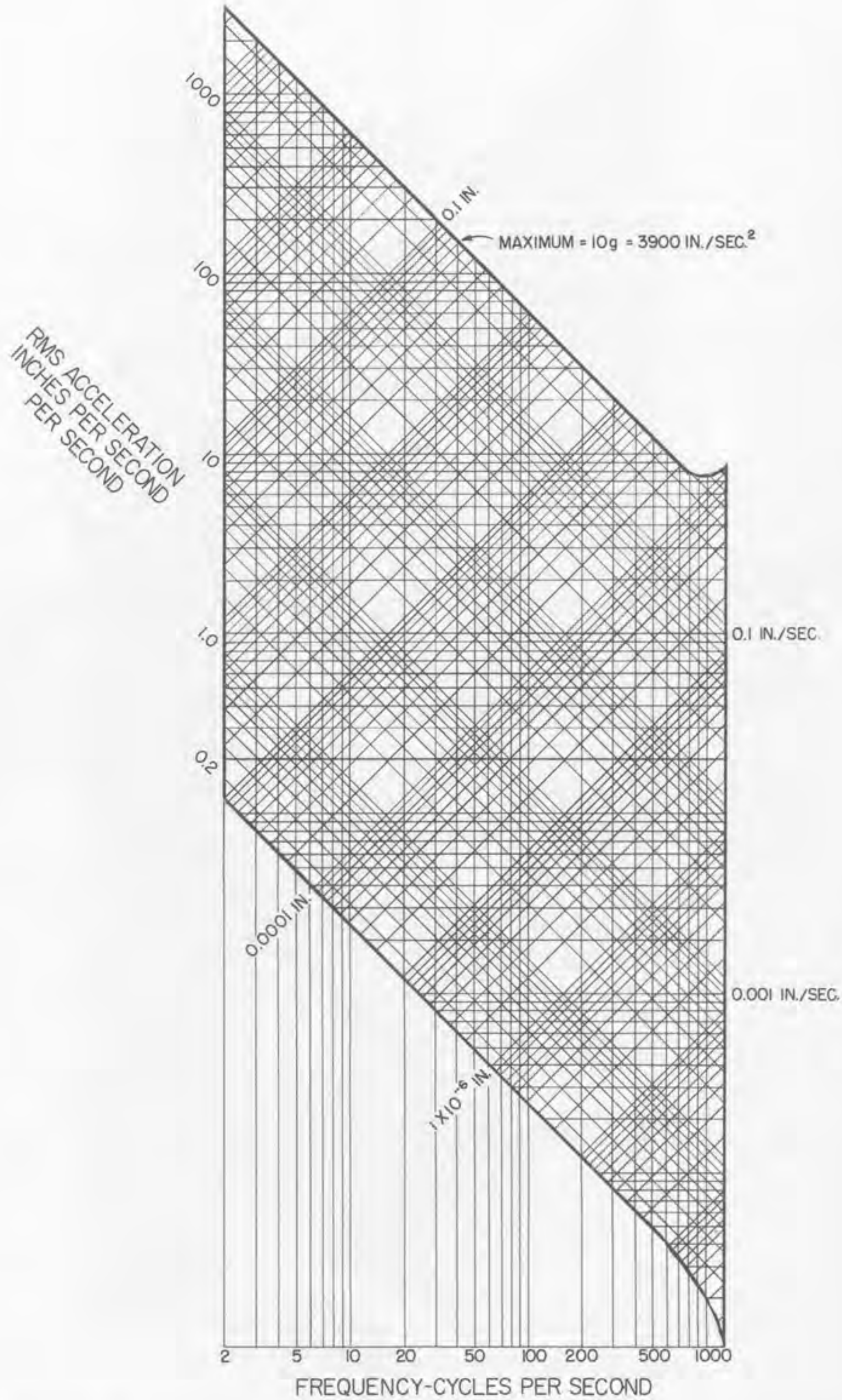


Figure 24. Direct-reading acceleration ranges of the Type 761-A Vibration Meter.

Figure 25. Range of vibration quantities that can be measured directly with the Type 761-A Vibration Meter, giving meter readings and corresponding values when frequency characteristics of instrument and pickup are applied.

FREQUENCY - CYCLES/SEC.		2		10		100		1000	
METER READS Switch Position		READING	VALUE	READING	VALUE	READING	VALUE	READING	VALUE
ACCEL. in./sec^2 x 0.01	Max. in./sec^2 Min. in./sec^2	3700 .16	3900 .17	3900 .16	3900 .16	3900 .16	3900 .16	4800 .16	3900 .13
VELOCITY μin./sec x 10	Max. in./sec Min. μin./sec			32* 160	39 195	6.2 160	6.2 160	.76 160	.62 130
VELOCITY μin./sec x 100	Max. in./sec Min. μin./sec	220 1600	310 2300	61 1600	62 1630	6.2 1600	6.2 1600	.76 1600	.62 1300
DISPLACEMENT μ in. x 1	Max. in. Min. μin.			0.8 16	1.0 20	.01 16	.01 16	.00012 16	.0001 13
DISPLACEMENT μ in. x 10	Max. in. Min. μin.	12.5 160	25 320	.95 160	1.0 170	.01 160	.01 160	.00012 160	.0001 130

*Maximum meter reading. All other maxima determined by 10g limit on crystal pickup.

Figure 26. Comparison of maximum meter readings of the Type 761-A Vibration Meter with the 10g limit of acceleration.

METER READS Switch Position	Cut-Off Frequency f_o	Meter Range	10g at f_o
ACCEL. in./sec^2 x 0.01	2	.16 to 32000 in./sec^2	3900 in./sec^2
VELOCITY μin./sec x 10	10	.00016 to 32 in./sec	62 in./sec
VELOCITY μin./sec x100	2	.016 to 320 in./sec	310 in./sec
DISPLACEMENT μ in. x 1	10	.000016 to 3.2 in.	1 in.
DISPLACEMENT μ in. x 10	2	.00016 to 32 in.	25 in.

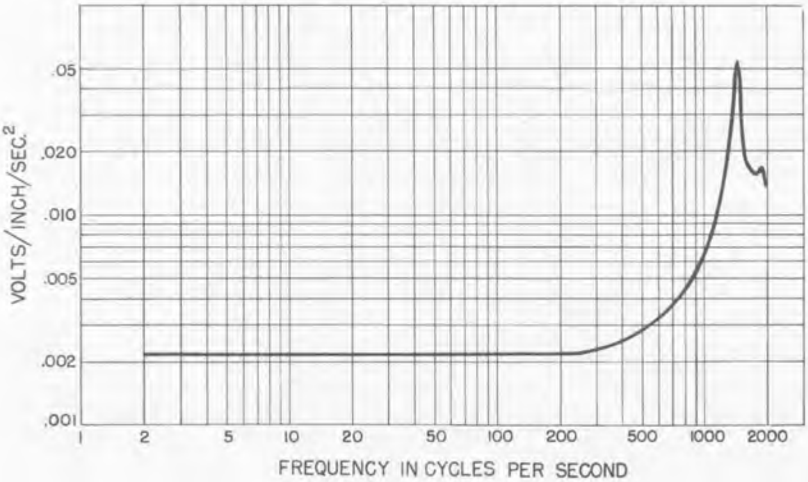


Figure 27. Frequency characteristics of a typical Type 761-P1 Vibration Pickup.

in the vibration pickup. As shown in the table of Figure 26 the maximum possible meter readings of the Type 761-A Vibration Meter exceed the safe readings for all positions of the METER READS switch except the VELOCITY x 10 position. This actually does not limit the velocity readings, since any value of velocity which falls above this meter reading can be read on the VELOCITY x 100 switch position.

Characteristics of Pickup

The Type 761-P1 Vibration Pickup supplied with the Type 761-A Vibration Meter is an inertia operated Rochelle salt crystal and it performs as an accelerometer. The frequency characteristic of this pickup is shown in Figure 27. As with all Rochelle salt devices, the maximum safe operating temperature for the vibration pickup is 115°F. Temperatures of 130°F and over result in permanent damage to the pickup. Measurements can be made on hotter machinery providing they are made quickly enough so that the pickup does not become heated. The long probe supplied as an accessory with the pickup will provide some heat isolation if the pickup must be used on equipment running at high temperatures so long as the ambient temperature is not above 100°F.

At lower temperatures the temperature characteristics of the pickup are similar to Rochelle-salt Piezo-electric microphones. Although the capacitance of the pickup varies widely as a function of temperature (see Figure 28), the sensitivity or output signal of the pickup varies in a more moderate fashion as indicated in the dotted curve of Figure 29. The solid curve of Figure 29 shows the performance of the pickup as a function of temperature when it is connected to the high impedance input of Type 761-A Vibration meter. The usual short cable supplied on the pickup does not require additional temperature correction, but, if a long extension cable is used, the added capacitance of the cable in parallel with the widely varying capacitance of the pickup causes a cable loss that is a function of temperature. The

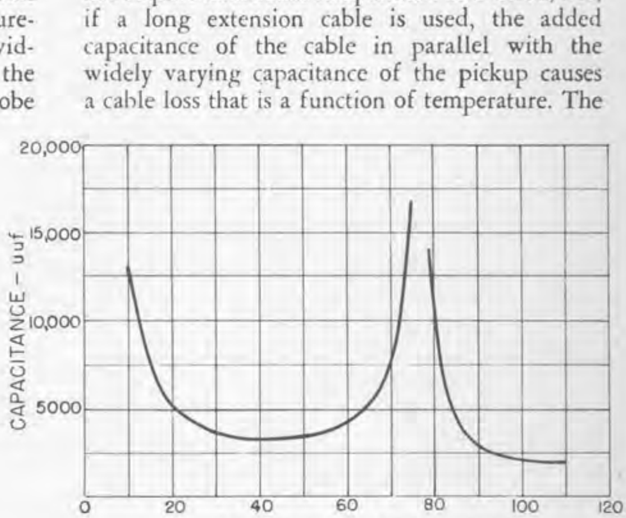


Figure 28. Capacitance of the Type 761-P1 Vibration Pickup versus temperature.

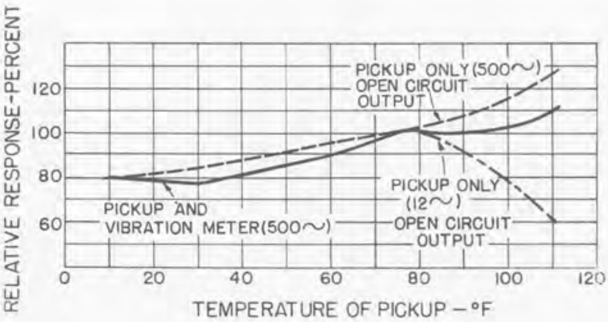


Figure 29.
Response-temperature characteristics of the Type 761-P1 Vibration Pickup.

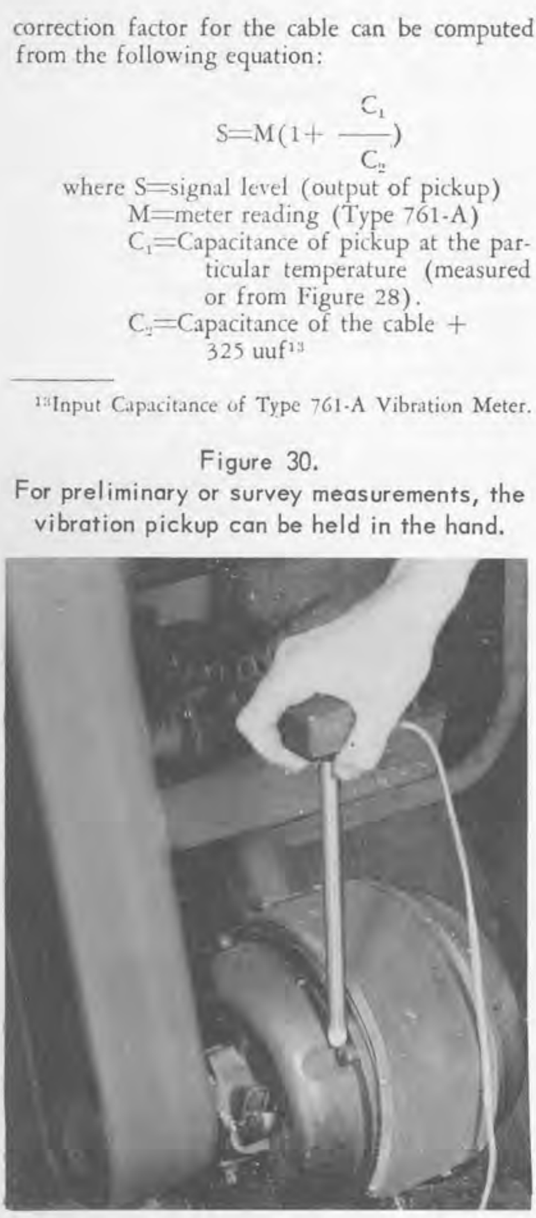
correction factor for the cable can be computed from the following equation:

$$S = M\left(1 + \frac{C_1}{C_2}\right)$$

where S=signal level (output of pickup)
M=meter reading (Type 761-A)
C_1=Capacitance of pickup at the particular temperature (measured or from Figure 28).
C_2=Capacitance of the cable + 325 uuf[13]

[13]Input Capacitance of Type 761-A Vibration Meter.

Figure 30.
For preliminary or survey measurements, the vibration pickup can be held in the hand.



For low-frequency measurements at high temperature, there is an additional undesirable change in the characteristics of the Rochelle Salt Vibration Pickup. The internal leakage resistance of the Rochelle Salt Crystal decreases as the temperature is increased. Above 100°F the leakage resistance may be reduced to just a few megohms. The loading effect of the resistance across the lowered capacitance of the pickup produces a large loss in low-frequency output from the pickup. This effect is illustrated by the lower dashed line curve of Figure 29.

Pickup Placement

The pickup responds most strongly to vibrations perpendicular to its front surface (the surface with the nameplate). A threaded socket (1/4-28 thread) is provided on this surface so that the pickup may be bolted or clamped in any desired fashion. A conical and a rounded tip are also provided, as is a long metal probe, all of which fit the threaded socket. The tips may be fastened directly to the pickup or to the end of the probe. By these means it is generally possible to hold the pickup against a vibrating surface or part, so that it will pick up the vibration satisfactorily. Sufficient pressure should be used on the pickup so that it follows the vibration accurately without chattering, but care should be taken not to push so hard as to affect materially the vibration itself. Hand-held operation is usually satisfactory for exploratory or preliminary work, but where a series of measurements is planned, or highest accuracy of results required, it is recommended that the pickup be bolted or clamped in place or in the places determined to be critical or important by preliminary hand-held measurements. Figure 30 shows how the pickup is normally used with the probe in making preliminary or survey type measurements.

It is very difficult to make hand-held direct reading measurements of small displacements, because the involuntary motions of the hand tend to swamp out the low displacement signals. Usually one is interested in very small displacements when the frequencies involved are fairly high. In such cases it is much easier to get consistent readings if the acceleration of the moving part is measured. Then the signals produced by the relatively slow motions of the hand have little or no effect on the results. The effect of hand motions is more severe when the long probe is used.

In vibration measurements where the acceleration is below 1g, it is often convenient just to place the pickup on its back. So long as the pickup does not rock or slip, it will measure the vibration that is perpendicular to its front surface. This technique is very useful in the measurement of vibrations of table or bench tops or of dynamic deflections in floors or decks of ships.

Another device, introduced to facilitate the application of the pickup is a small powerful permanent-magnet-type clamp (MAP-2-S1), Figure 31, that attaches to the pickup in place of the probe or tip. This magnetic clamp is especially useful when making vibration measurements on machinery where hand-held operation of the pickup is not too satisfactory, and where it is not always possible to clamp or to bolt the pickup in place. In places where a flat area the size of the magnet can be found, the MAP-2-S1 magnetic clamp will hold the pickup satisfactorily for both vertical and horizontal vibrations with accelerations up to 10g.

Choice of Characteristic

The choice of displacement, velocity, or acceleration depends upon the use for which the data are needed and the considerations mentioned in

Figure 31. The vibration pickup held in place simply by means of a permanent-magnet clamp which replaces the probe or tip.

Chapter II. Typical examples of applications for the different types of measurements are as follows: *Displacement* measurements are widely used in measuring ship vibrations and vibrations in heavy machinery. *Velocity* measurements are used for measuring sound transmission through walls, or the sound radiated by large surfaces such as power transformer shells, etc. *Acceleration* measurements are used in most machinery noise problems or where parts are liable to fail as a result of the vibrations.

In all cases it should be remembered that acceleration measurements give the greatest emphasis to the high frequency components, and displacement measurements give equal emphasis to all components within the normal frequency range of the measuring equipment.

HOW TO USE THE VIBRATION ANALYZER

Relative Readings

All batteries for operating the vibration analyzer are contained within the case. Push buttons and a neon lamp on the panel indicate when the batteries should be replaced. The instructions mounted in the cover of the instrument should be followed.

Tuning is accomplished by the large knob and the push button range switch. The calibration is direct reading in cycles per second and may be converted to rpm by multiplying by 60.

A cable is provided to connect the input of the analyzer to the output of the vibration meter. For relative readings, the 0-to-120 scale is most convenient, and the sensitivity control on the vibration analyzer should be set so that for the strongest component of the vibration the reading is 100. This should be done with the vibration meter so adjusted that a normal indication is obtained on the indicating meter of that instrument.

The best procedure for setting the sensitivity control of the analyzer is as follows:

(1) Press range button A (2.5 to 7.5 cycles) and turn the main analyzer dial slowly, noting the deflections of the meter or the analyzer.

(2) Repeat, covering the entire range of the instrument by successively pressing buttons B, C, D, and E, and turning the dial around. The dial may be rotated continuously in one direction.

(3) During this process the SENSITIVITY control on the analyzer should be turned down whenever a component is found that deflects the meter above 100, so that the meter reads 100 exactly. This sets the sensitivity such that the analyzer will read 100% on the strongest component in the vibration. *Do not change the setting of this control before completing the analysis as outlined in step 4.*

(4) The analyzer should then be tuned for maximum amplitude on each successive component (without resetting the sensitivity control) and the results recorded directly in terms of frequency and percentage of the amplitude of the strongest component. The procedure is exactly the same as for the Type 760-B Sound Analyzer. Because of the inherently slow response of highly selective low-frequency circuits, a METER RETURN button is provided. When the operator has tuned the analyzer away from a component, pressing this button will return the meter reading quickly to zero.

The vacuum-tube voltmeter circuit included in the vibration analyzer provides a semilogarithmic scale on the indicating meter, so that the entire usable range of the instrument may be obtained without additional multipliers, etc. The controls of the vibration meter and the SENSITIVITY control of the vibration analyzer should not be readjusted during the analysis.

The analyzer is equipped with an output jack for operating ear phones, which may be used for listening to the component being measured, if it is of audible frequency.[14]

Absolute Readings

For most purposes, relative readings are sufficient, but absolute readings may also be made with the vibration analyzer if desired. For absolute readings, the calibration procedure is as follows:

(1) Connect the vibration meter to the 60-cycle line as when adjusting its calibration.

(2) Connect the analyzer to the vibration meter in the normal manner.

(3) Depress the button marked CALIBRATE 1 on the vibration meter and tune the analyzer

[14]Because of the a-v-c characteristics of the vacuum-tube voltmeter circuit, the output applied to the phones is not a pure sinusoid. Hence some output may be heard at very low frequencies which would normally be inaudible.

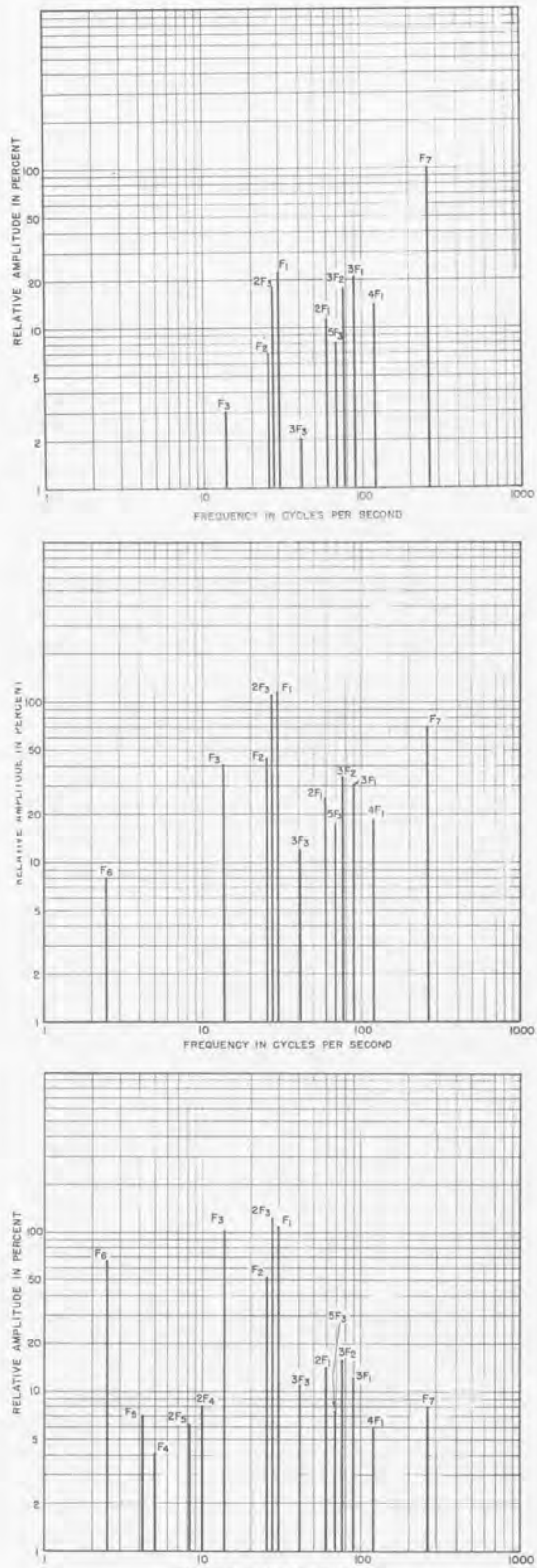


Figure 32.

Typical analyses of machinery vibration, showing (top) acceleration, (center) velocity, and (bottom) displacement measurements as made on a single machine under the same conditions. These illustrate the complexity of the vibrations which can be analyzed with the vibration analyzer, also the differences in the importance of the various components in measurements of displacement, velocity, and acceleration.

to maximum response at the power-line frequency.

(4) Adjust the analyzer sensitivity control so that the meter on the analyzer reads the same as the one on the vibration meter.[15] It is desirable to mark this calibration point on the sensitivity dial of the analyzer with a pencil so that it can be returned to if the control is accidentally shifted. The control should be left at this point and not readjusted during an analysis.

(5) After the analyzer sensitivity is set, the vibration meter should be disconnected from the power line and adjusted for normal reading on the vibration to be analyzed. The analyzer may then be tuned to the various components of the vibration, the meter of the analyzer being read in exactly the same way as the meter of the vibration meter, using the readings of the METER SCALE knob and the multiplier factors of the push buttons on the vibration meter. The SENSITIVITY control on the vibration analyzer should not be readjusted, but should be left at the setting that gave a deflection of the meter equal to that of the vibration meter during the calibration as outlined in (4) above.

The red scale on the analyzer should be used when the METER SCALE knob of the vibration meter is set at a red point and the black scale when the knob is set at an uncolored point. The analysis will then be in terms of the same absolute values as the vibration meter reading, and the same multiplying factors will apply.

Displacement, Velocity, and Acceleration

The analysis will be made in terms of displacement, velocity, or acceleration, depending upon the setting of the vibration meter. Choice among these different characteristics should be based upon the same considerations as when measuring the overall vibration as described in Chapter II and in the foregoing section outlining the use of the vibration meter.

Figure 32 shows typical machinery analyses as made with the Type 761-A Vibration Meter, and the Type 762-B Vibration Analyzer for (a) displacement, (b) velocity, and (c) acceleration. The changes in relative amplitudes of the various components for the different types of measurements are clearly shown.

When the Type 762-B Vibration Analyzer is used at the output of the Type 761-A Vibration Meter to indicate absolute values of displacement, velocity, or acceleration, the accuracy of converting from velocity or acceleration readings to displacement values as outlined in Chapter VI, can be increased since a single component of a complex wave is selected, and the frequency of that component can be read from the analyzer frequency dial.

The use of the Type 762-B Vibration Analyzer is not limited to the analysis of the output of the Type 761-A Vibration Meter. It can be used with practically any vibration meter for analyzing either linear or torsional vibrations.

In addition, the Type 762-B Vibration Analyzer can be operated directly from a number of velocity pickups. For example, at velocities of 1 inch/sec and higher the output from the following self-generating velocity pickups will produce full scale reading on the Vibration Analyzer: CONSOLIDATED[8] Types 4-102A, 4-103, 4-106V, 4-106H, 4-118 and MB[16] Types 120, 122, 123, 124, 125, 126, 127, 128, 132, 133, 134 and 135.

Type 1551-A Sound-Level Meter with 759-P35 and 759-P36 Vibration Pickup and Control Box

Operation of the Sound Level Meter with a vibration pickup and control box is very much the same as operation of the Type 761-A Vibration Meter. The readings obtained are, however, in terms of decibels and one must use the decibel conversion tables supplied with the pickup and control box, or in Appendix 1, to convert the decibel readings to the useful vibration terms of inches or μinches for displacement, inches per second for velocity, or inches per second per second for acceleration. The same vibration pickup is used in each case, but the amplifiers in the Sound Level Meter limit the useful low-frequency response to 20 cycles per second. The upper frequency limit of measurement which is determined by the pickup is 1200 cycles per second (see Figure 7, Chapter III). The maximum vibration level safely measured, again determined by the pickup, corresponds to an acceleration of 10g.

[15] On currently produced vibration analyzers the red and black scales track the same as on the vibration meter. On very early models the scales are slightly displaced. With these latter analyzers two positions of the sensitivity control should be determined, one for the red and one for the black, if maximum possible accuracy is desirable. Otherwise an average setting is satisfactory.

[16] MB Manufacturing Co., Inc., New Haven, Connecticut.

CHAPTER VII

EXAMPLES OF TYPICAL VIBRATION MEASUREMENTS

The following accounts of vibration measurements are reports made to General Radio by engineers who have used General Radio Vibration-Measuring Equipment to help them in solving vibration problems with which they have been confronted. It is hoped that the information included in this part of the booklet will help the reader to see how the readings and measurements taken with the vibration-measuring equipment can be used and evaluated in the process of analyzing and solving typical vibration problems as they occur in practice. The examples cited here do not illustrate all possible uses of the equipment described in the earlier parts of the booklet. Neither do they illustrate unique solutions to the problems presented. The imagination, ingenuity, and skill of the engineer faced with a particular vibration problem are still as important as the tools used to arrive at a satisfactory solution.

RESONANT VIBRATION IN LARGE ENGINE FOUNDATION

By G. M. Dexter[17] and M. K. Newman[18]

Vibration in a large concrete foundation that was in near resonance with the gear mesh frequency of a pinion on a large Corliss engine was analyzed successfully with the aid of the vibration meter and sound analyzer of the General Radio Company. The problem arose on mill engine No. 2 on the grinding tandem of the U. S. Sugar Corp., Clewiston, Florida. This grinding tandem consists of a set of revolving knives, a 2-roll crusher, and seven 3-roll, 78-inch mills.

Engine No. 2 is a 36-inch by 60-inch Corliss engine that operates at 40 to 70 r.p.m., depending on the amount of sugar cane being crushed and its fiber content. Recent examination showed that its concrete foundation was vibrating badly and that the amount of vibration increased with the load on the grinding tandem and with the speed of the engine.

The engine is one of three on a large concrete foundation, about 145 ft. long, 40 ft. wide, and 11 ft. thick for over one-half its width. This engine drives three mills of the grinding tandem through a set of five large gears and three pinions. The foundation is on the typical muck on sand on porous rock of the Everglades where the water level is about three feet below the surface. The unusual nature of the soil made the problem more difficult. Although there is a definite friction against lateral movement of water, an irregular lateral movement does take place in the soil.

The first reaction to the vibration problem was that the concrete foundation by settling unequally was causing misalignment of gears that produced vibration. Four deep wells nearby were a part of the problem as they drew about 550 gallons per minute and caused a cone of depression in the ground water level that extended under the concrete foundation. Weekly level readings on various control points on the concrete foundation and ground water level were started to determine whether any settlement was actually taking place. An analysis of the load on the soil from the foundation and its machinery showed that the load was fairly well distributed and was about 0.8 tons per square foot. This amount is well within the limit that experience has shown to be safe for Everglades conditions where drainage ditches are in use.

[17]Engineer for Bitting, Inc., New York, N. Y., Supervisory Managers, U. S. Sugar Corp.

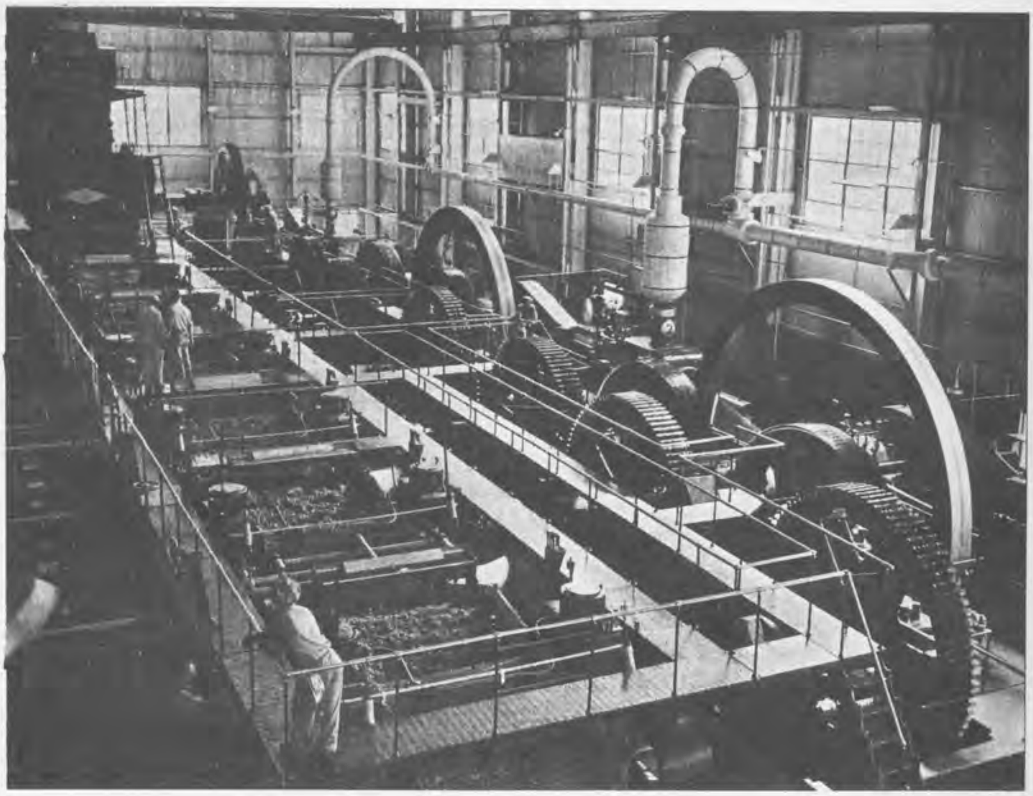
[18]Physics Dept., Columbia University, New York, N. Y.

While the preceding work was under way, a vibration meter and a sound or wave analyzer of the General Radio Company were brought into use by Mr. M. K. Newman. He found that the vibration of the mill engine foundation could be broken down with the sound analyzer into several frequencies, one of which was identical with the frequency of the gear mesh of the main pinion on engine No. 2, the others being multiples of this frequency. All frequencies in the foundation varied with the speed of engine No. 2. The vibration meter permitted the determination of amplitudes of vibration, velocities, and accelerations due to each frequency. The frequency spectrum of the amplitudes showed that the most important effect was that due to the single-mesh frequency of the main pinion on engine No. 2. This vibration was found to exist throughout the foundation. A complete response characteristic of the foundation was taken up to the highest engine speeds used and a definite resonance peak was found for a constant vibrating force at a frequency corresponding to an engine speed of about 68 rp.m.

The preceding fact immediately suggested that the pinion might be at fault. Measurements were taken that showed the pinion was in poor alignment with the two large gears it drove. Plaster of Paris casts of the teeth of the pinion and the two gears it drove showed they were worn.

A calculation of the foundation modulus by means of a method developed by M. A. Biot for an infinite beam on an elastic foundation (Journal of Applied Mechanics, May, 1937) and the use of methods outlined by S. Timoshenko in "Vibration Problems in Engineering" showed that the mill-engine foundation had several natural frequencies that were very close to frequency of the gear mesh of the main pinion on engine No. 2. The forced vibration problem was solved for a beam on an elastic foundation. The nine lowest modes of vibration were found to contribute appreciably to the resulting vibration, with the second harmonic in bending predominant because of near resonance. The resulting distribution of amplitude of vibration showed the same typical form that was obtained with a Davey Vibrometer. These data supported the conclusion

Figure 33. The grinding tandem of the U.S. Sugar Corporation at Clewiston, Florida. Mill engine No. 2 is the center unit.



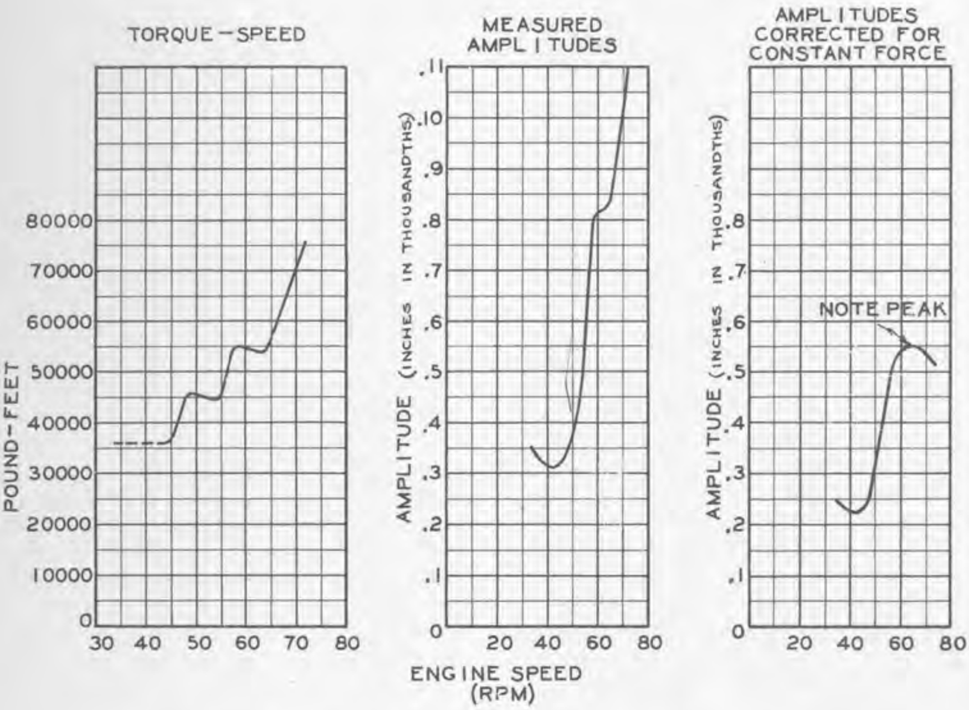


Figure 34. Compound amplitudes at engine No. 2 as measured on concrete foundation with the Type 761-A Vibration Meter.

reached with the instruments of the General Radio Company that the mill-engine foundation was in near resonance with the gear-mesh frequency of that pinion. In other words, the amplitudes of the vibration of the concrete foundation were greatly magnified.

The level readings also showed that two or three points near engine No. 2 on the foundation settled at high speeds of that engine but did not at low speeds. This fact is confirmation of the conclusion that settlement is due to vibration. Amplitude of vibration was a little more than 0.001 inches at a frequency of about 30 cycles per second.

In addition to the preceding, numerous other studies were made such as possible wabble of the flywheel of engine No. 2, possible loose foundation bolts in the base plate of the engine, stresses in gear teeth due to the heavy load on the grinding tandem, etc. A detailed discussion of all that was done is out of place here.

The meters of the General Radio Company were selected only after a definite search had been made for meters that could be used to analyze vibrations encountered in part from an unusual soil condition. Their successful application to this problem opens up a new field of investigation on the behaviour of concrete foundations under vibrating loads. This account is probably the first description of the application of the meters of the General Radio Company to a problem in the resonant vibration of a concrete foundation. With those meters, it was possible to analyze the problem so definitely that the cause and cure of the vibration could be given with considerable certainty.

ANALYSIS OF VIBRATION PROBLEM IN POWER PLANT BUILDING

This report presents the measurements made and the conclusions arrived at in an investigation of a vibration problem in connection with the power plant of a New England institution. Briefly, the problem can be summarized as follows: Two new steam-driven reciprocating a-c power generating machines had recently been installed in the power plant building. When the new steam engines were in operation, excessive vibration was noticeable throughout the entire building in which they were located. These two electric power generators were to be used in connection with a new building to be constructed at a distance of about 200 feet from the power house. In addition to analyzing the local vibration problem in the power plant proper, it was necessary to investigate the anticipated vibration conditions in the new building owing to operation of the steam engines in the power plant.

The power house contained four large power-generating steam engines, two large boilers and many smaller engines on the ground floor. Other facilities of the institution occupied the second and third floors of the building. The power house was of pre-1900 construction, and the flooring in the area above the steam engines was of wood construction. The building sat on a foundation of sand and water with the water level approximately 10 feet below the surface. The basement floor of the proposed new building will be about five feet below the water level.

The four reciprocating steam engines in the power plant consisted of (1) a four-valve, one-cylinder engine running at 180 rpm, generating 250 kilowatts of d-c power; (2) a piston valve, one-cylinder engine operating at 270 rpm and developing 100 kilowatts of d-c power; (3) two recently installed, two-cylinder, vertical-type engines direct coupled to a 600-kilowatt a-c generator operating at 327 rpm.

Each of the new engines was on a separate concrete slab 12 ft. x 18 ft. x 7 ft. deep and 6 ft. in the ground. This slab formation was isolated from the main floor slab by a one inch, mastic filled gap. The two-cylinder engine had a piston diameter of 18½ inches and a stroke of 16". It operated with a steam pressure of 175 lbs/sq. in. on the intake and exhausted into a line set at 5 lbs/sq. in. Each engine had a separate steam line from the boiler. This feed line was eight inches in diameter and made several 90° bends over a distance of approximately 50 feet between the boilers and the engine. The exhaust pipe for each new engine was 12 inches in diameter and split into two 12 inch branches immediately after leaving the engine. One branch from each engine went directly to the roof of the power house and operated as a bleeder. The other exhaust branches made about three 90° bends before going under the floor between the two engines. Immediately under the floor the two exhausts joined together and traveled for a distance of 75 to 100 feet to a pump room at the other end of the building. The pipe then rose vertically about 15 feet to an oil separator tank and to the radiator supply for the main building of the institution. An atmospheric bleeder, mounted on the roof of the power house, immediately followed the oil separator tank. Most of the steam lines in the power house were mounted on hangars attached rigidly to the ceiling of the first floor.

Measurements and Results:

A series of vibration measurements was taken at and around the power plant to determine the source of the disturbing vibrations and to determine the vibration levels that could be expected in the proposed new building. These measurements were taken with the following General Radio vibration measuring equipment:

Type 761-A Vibration Meter
Type 762-B Vibration Analyzer

Vibration measurements were made on the foundation of one of the new engines while it was operating to determine its amplitude of vibration. Because the two cylinders in the steam engine are operated 180° out of phase and double acting, it was expected that a considerable amount of rotational vibration (see Chapter IX) might exist in the slab on which the engine rested. However, measurements indicated that there was almost no rotational vibration and that all the vibration was translational. The vertical translational vibration of the slab under this engine showed a peak to peak displacement of only 1.5 mils (0.0015 inches). This maximum displacement of 1.5 mils occurred at frequencies of both 5 and 10 cps, depending on the location with respect to the engine. The vertical displacement of the isolated floor slab right next to the engine foundation had a displacement of approximately 1 mil. A 12" x 12" building stanchion was erected between the two new engines at the time the engines were installed to reinforce the floor above. This vertical stanchion was found to have a maximum displacement of 1.5 mils in the horizontal direction. The wooden floor directly above this stanchion had a vertical displacement of 3 mils. The floor vibration was in the 6 to 10 cycle region. A check on the acceleration showed that this floor had an r-m-s acceleration of 1 ft/sec² (.031 g). Personnel working in an office on the southeast corner of the third floor had complained about vibration when the two new steam engines were in operation. It was interesting to note that the vibrations on the floor in this office were substantially the same most of the time (about 3 mils) whether or not the two new engines were operating. However, when the phasing of the two new engines became just right, the displacement of the floor in this office got as high as 10 mils. It was further determined that the bleeder or exhaust pipes for the new engines were tied to the building structure immediately under this third floor office.

Near the top of the engines, where the supply and exhaust pipes connected with the engine, the engine rocked back and forth with a maximum displacement of 6 mils. The 8" steam supply line for each of the engines was hung on rigid hangers from the wooden floor above. At one of these hangers about a third of the way back to the boiler it was found that the rigid hanger had a vertical displacement of 12 mils. On the 12" exhaust pipe there were horizontal displacements of 8 mils, just 6' from the engine. As stated before, the exhaust pipe from the two engines traveled in a pit underground along the long axis of the building, practically to the other end of the building (a distance of 75 to 100 feet) whereupon it made a bend into a vertical run. At this bend, which occurred in the pump room, the pipe was found to be elongating through a horizontal displacement of 30 mils. Also in the pump room a small turbine pump fed into the common exhaust line. The small pipe connected with the pump was set into sympathetic vibration, with a displacement of over 100 mils, by the 10-cycle pulses in the steam line from the new engines.

Measurements were made on soil conditions and in the ground at various distances from the new engines. As stated earlier, it was found that the foundation of one engine had a vibration amplitude of 1.5 mils. This value decreased to an amplitude of .18 to 0.3 mils at points 300' from the power house at the position of the nearest wing of the proposed new building. From studies of the engine and soil conditions it was determined that the engine should produce an amplitude of vibration in the soil of about 1 mil. It was also found, from calculations based upon the size and weight of the foundation and upon measured characteristics of the soil, that the natural frequency of each new engine with its foundation in combination with the soil was between 8.5 and 11.2 cps (operating frequency 10 cps).

The vibration measurements made on the walls and floors of the building and upon the piping system indicated that the piping was responsible for the excessive vibration experienced in the power plant building itself. On the other hand, the measurements indicated that the residual vibration levels at 300' were coming from the base of the engine.

It was concluded that there was little chance of the vibrations being objectionable in the new main building unless a direct concrete or masonry tie was made between the two buildings. It was recommended that steam tunnels between the power plant and the new buildings should have mastic vibration breaks at several points along their lengths and that steam and water pipes should be rigidly clamped at some point in the tunnel in order that vibrations would not be transmitted to the new buildings from the power house.

Possible modification of the engine foundations was prepared in case it was felt necessary, at a later date, to move the resonant frequency of engine, slab, and soil combination away from the 10 cps. operating frequency. The proposal would increase the mass of the engine foundations and would tie the two foundations together so they would act as a single unit. Calculations on the proposed modification indicated that the resonant frequency would be lowered by a factor of 1.4 and that the amplitude of vibration transmitted to the ground might be decreased by as much as 6 to 1.

To confirm that the vibrations in the walls and the upper floors of the power house were induced by the vibrations of the pipes and not by vibrations traveling through the foundations of the engines the following experiment was performed. A vibration-isolating sleeve was installed in the steam intake pipe and a second vibration-isolating sleeve was installed in the steam exhaust pipe. The two new engines were decoupled from the wall of the power house by removing expansion joints between the piping and the blow off valve mounted on the wall. The piping in the long steam tunnel was securely anchored so that it could not move.

Vibration measurements at once revealed a very bad resonance condition in the piping immediately following the exhaust port on the engine but preceding the newly added vibration isolator. Since the piping had been decoupled from the walls, the vibration from this resonance condition did not get into the walls of the building so that the annoying and dangerous conditions existing prior to this time were eliminated.

The vibration isolator had been added just beyond a large valve in the exhaust piping. From the exhaust port of the engine to this valve the piping was acting as a cantilevered beam loaded with the heavy mass of the valve. This beam had its natural resonance frequency at almost exactly 11 cps. It was found, for example, that by changing the speed of the new engine from 300 rpm to 350 rpm, the vibration of the piping at the valve went from 8 mils to a maximum of 30 mils and then down to 8 mils.

The isolation of the piping from the wall reduced the measured vibration at the base of the engine from 1.5 mils to 0.35 mils. In other words, the vibrations measured at first at the engine base did not originate in the foundation and soil combination but originated in the piping that was connected to the side wall and were thence transmitted down to the foundation of the machine.

Measurements made on the wooden floor above the engines after isolation of the piping from the power plant walls showed that the displacement was about 1.3 mils compared with the previous measurements of 3 mils. Further tests showed that the new engines were accounting for no more of the vibration than was the old equipment which was in operation at the same time.

The complete solution of this vibration problem involved installation of vibration-isolating sleeves in the intake steam pipes to the new engines, installation of vibration isolating sleeves in the exhaust lines immediately following the exhaust ports of the engines, and installation of surge tanks or mufflers in the exhaust lines following the vibration isolators. The mufflers were added to remove the steam pulses which were causing excessive vibration of the piping in the pump room located at the far end of the steam tunnel.

LOCATION OF FAULTY STEAM TRAPS WITH A VIBRATION PICKUP

Efficient steam trapping is necessary for the economic use of steam and the use of traps enables the plant engineer to get the most practical use from each pound of steam. The traps used at General Radio Co. are of the balanced-pressure thermostatic type illustrated in Figure 35.[19]

Five hundred of these traps in various sizes and makes are used throughout the plant. To maintain efficient operation of these traps, the manufacturers recommend that they be replaced every five years. In order to heat our plant satisfactorily during the winter before these traps were all changed some five years ago it was found necessary to fire up a stand-by boiler as well as the two regular working boilers. In addition, on very cold nights, it was necessary for the fireman to open up the fires as early as 1 or 2 o'clock in the morning in order to have the buildings warm by 8:30 or 9:00 a.m. After the traps had been replaced, the two regular boilers took care of the heating load with ease. Even on the coldest nights the fireman had no trouble getting the buildings warm at the start of working hours if he opened up his fires by 5:00 a.m.

Replacing traps in a wholesale manner, whether or not they are defective, is an effective, but wasteful method of solving the problem. Open-air listening tests without instrumentation are useless in the presence of ordinary factory noises. Fortunately, a vibration pickup plus a sound-level meter[20] and earphones offers a particularly effective means of spotting defective traps. The vibration pickup serves to transmit to the sound-level meter or vibration meter the sounds produced by steam and water in the pipes and trap. With a little practice, the hearing mechanism of the operator becomes a reliable, calibrated analyzer and can readily pick out the traps that are not functioning properly.

This instrumentation is particularly useful in testing the traps located in mains where the steam cannot be shut off during the normal working day. Faulty traps can be located and then when the steam is off for other reasons or when it is convenient to shut the steam off for this purpose the trap can be replaced.

During the past year, the listening tests on the steam traps have found some sixty defective traps. The cost of these traps and the man-hours needed to replace them were much less than would be needed to replace all 500 traps as was the previous practice. It was felt that, while it improved efficiency of the steam system to change the traps every 5 years, many traps were being changed before their useful life was ended and this was needlessly expensive both in dollars and man-hours. Also, traps which became defective in less than five years were reducing efficiency of the system. The results obtained to-date have justified this feeling. By this relatively low cost instrumentation much time and money has been saved. The steam plant has been kept at maximum efficiency, and the full useful life of the steam trap is attained. Not only has the instrumentation been used in routine checks on the steam traps but it has been useful in locating the source and location of water-hammer.

We recently heard of a new plant in which by the end of one year's operation 6 or 8 steam traps in quiet locations were defective. On the basis of this finding all steam traps in the plant were exchanged. Here, much time and money could have been saved had the plant engineer been aware of the available instrumentation.

[19]Kenneth G. Oliver, "STEAM TRAPPING," Instruments & Automation, Vol. 27, No. 3, March 1954, pp. 470-473.

[20]A Type 761-A Vibration Meter can be used just as effectively.

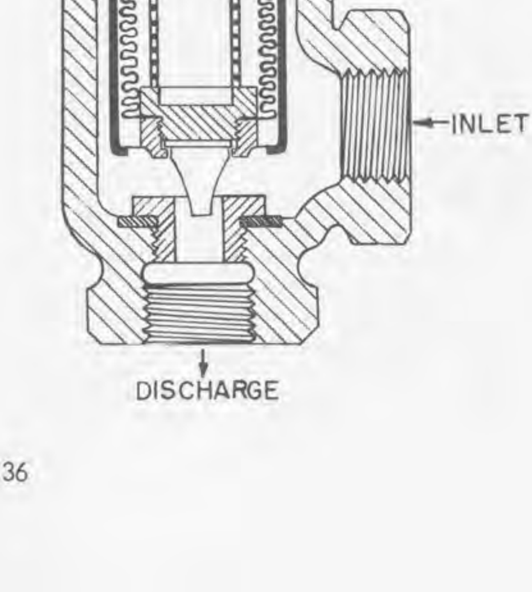


Figure 35. Cross section of a balanced-pressure thermostatic steam trap.

Calibration and Measuring Technique:

To make useful measurements, the over-all measuring system including the operator first had to be calibrated. The vibration pickup, with its long probe and conical tip attached, was held on the cap of a steam trap located at the end of a radiator that could be shut off. The long probe and tip was used to keep the Rochelle Salt Crystal unit away from the hot steam pipes. Calibration procedure was then as follows:

1. Shut off radiator and allow time for the Vacuum pump to evacuate the radiator.
2. With pick-up probe at top of steam trap, adjust attenuator on Sound-Level Meter until panel meter reads on scale.
3. Plug phones into output jack of Sound-Level Meter and listen to signal being picked up. (This is the background noise in the piping system with theoretically nothing passing through the trap.)
4. Turn radiator on and listen for:
   a. The swish of air rushing through the pipes.
   b. The gurgle of water being pushed along the pipes.
   c. The steam trap to close. If the trap is working correctly, the sound will return to that heard in 3 above. If trap is not working correctly, the hiss of steam leaking through the trap can be heard above the level heard in 3.

Figure 36. Checking a steam trap with vibration-measuring equipment.

DIRECT WRITING RECORDER USED WITH VIBRATION METER TO MAKE VIBRATION ANALYZER

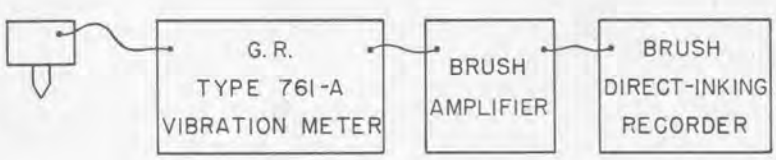
As mentioned in Chapter IV, the recording galvonometer is a tool widely used in vibration measurement and analysis. Presented here to show the nature of the results one can obtain are photographs of four records taken with a popular recorder which uses a direct writing pen motor. This recorder produces an inked record. These records are only a few of many taken during the course of a vibration study made in a large industrial plant. The instrumentation used for this vibration study as shown in the block diagram of Figure 37 was one General Radio Co. Type 761-A Vibration Meter with a Type 761-P1 Vibration Pickup, one Brush[21] Model BL-201 single channel oscillograph, and one Brush Model BL-905 amplifier.

For all measurements the Type 761-A Vibration Meter was set to read displacement and the attenuator set for a full scale reading of .003 inches rms. The Brush Amplifier settings were: Voltage calibration control=5, attenuator=1, and gain adjusted to give 1mm/volt deflection on the recorder at 60 cps. With the amplifier connected to the output of the vibration meter and the vibration pickup placed on a Syntron Vibrator the following overall calibration was obtained by varying the 60 cycle Voltage applied to the Syntron Vibrator:

Reading of Vibration Meter rms. inches	Deflection of Recorder m.m. either side of center
.001	3
.002	6
.003	9

[21]Brush Electronics Company, Cleveland, Ohio.

Figure 37.
Block diagram of instrumentation used to obtain Figures 38 to 41.



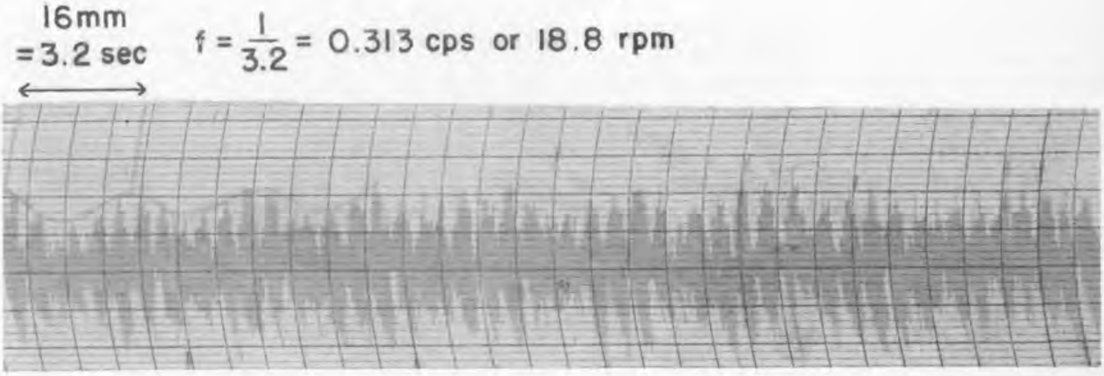


Figure 38. Record of vibration displacement on pressroom floor (all presses running) made with a direct-writing recorder – chart speed 5 millimeters per second (see text).

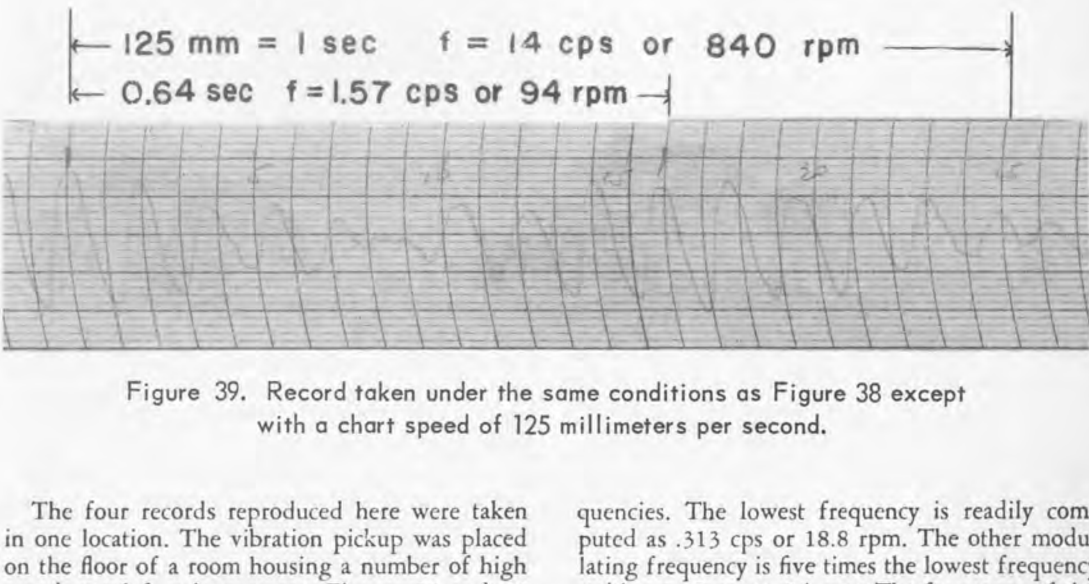
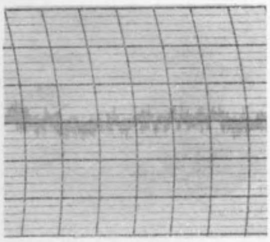


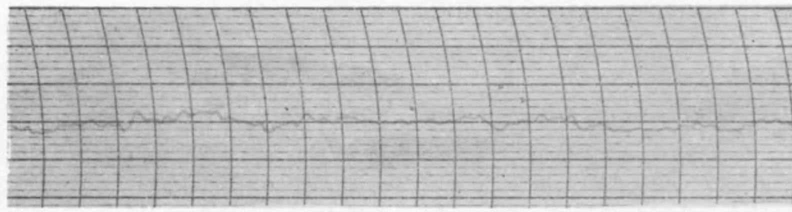
Figure 39. Record taken under the same conditions as Figure 38 except with a chart speed of 125 millimeters per second.

The four records reproduced here were taken in one location. The vibration pickup was placed on the floor of a room housing a number of high speed metal forming presses. Figures 38 and 39 are records made with all presses running while Figures 40 and 41 are records made with all the presses stopped.

The two records shown above are for the same vibration, but the information that can be derived from the records is not the same. The record in Figure 38 was taken at a chart speed of 5 mm/sec. We can see quite clearly that it was a distinct advantage to have the different chart speeds available. From the two records we can get a reasonably complete analysis of the complex vibration wave-form while neither record by itself can tell us the whole story. From Figure 38 we can determine that the vibration wave-form looks like a carrier frequency modulated by two lower frequencies. The lowest frequency is readily computed as .313 cps or 18.8 rpm. The other modulating frequency is five times the lowest frequency making 1.57 cps or 94 rpm. The frequency of the carrier cannot be determined from Figure 38. Figure 39, which is stretched out by a factor of 25 to 1, yields the carrier frequency at 14 cps or 840 rpm and verifies the higher modulating frequency as being 1.51 cps. The lowest modulating frequency is not recognized in Figure 39.

Figures 40 and 41 show the residual vibration of the factory floor after all of the presses had been shut down. Figures 40 and 41 should be compared respectively with Figures 38 and 39. The vibration amplitude is now well below .001 inch and no periodic modulating frequency is easily recognized. The record in Figure 41 indicates that the residual vibration is not sinusoidal and that it is 60 cps (3600 rpm) or higher.





(Left) Figure 40. (Right) Figure 41. Residual vibration recorded on pressroom floor with all presses stopped - chart speeds 5 and 125 millimeters per second respectively.

Records reproduced by courtesy of United Carr Fastener.

CHAPTER VIII

HUMAN RESPONSE TO MECHANICAL VIBRATION

The question has often been asked, "Are curves available that relate man's response to mechanical vibrations as a function of amplitude and frequency in the same way that the Fletcher-Munson[22] curves relate man's response to pure tone sounds as a function of pressure level and frequency?" This question is important to those who are concerned with passenger or operator comfort in automobiles, planes, boats, trains, or other vehicles. Vibration levels that are structurally safe for a vehicle are often uncomfortable, annoying, or even dangerous for the occupant. In military vehicles it may not be all important that the occupant be comfortable but it is certainly important that excessive vibration does not cause fatigue and reduce sharply the efficiency of personnel.

There are no curves which present as completely the human responses to vibration as do the Fletcher-Munson curves for human responses to pure tones of sound. Several news releases[23] indicate that the U. S. Navy plans to study the effects of mechanical vibration on man. A "Large Displacement—Amplitude Vibration Machine" has been developed and built at the Naval Medical Center, Bethesda, Md. This two-ton machine is designed for a maximum load of 200 lbs. at any combination of displacement (0 to 4 inches) and frequencies (2 to 50 cps) not exceeding 15g peak acceleration. In the words of one reporter "the engineering principle involved likens this project to a number of units currently being operated in New York City. In New York they call them subways."

Some information of this type has already been published. A complete story neatly summing up all the desired information is not available. Goldman[24] has surveyed and attempted to correlate the data of a large number of investigators. From this data he derived the three solid curves I, II, and III shown in figure 42 which represent respectively the threshold of perception, the threshold of discomfort, and the threshold of tolerance or the level of intensity at which the subject for any of numerous reasons was unwilling to tolerate the stimulus further. All workers did not make their measurements over the same frequency range or over the same intensity range. Also each worker used his own apparatus and his own method of exposing his subjects. In many cases duration of exposure was not clear. The data were grouped without reference to the direction of the vibration, since examination of the data showed that differences due to the direction of application of the vibration were smaller than differences due to statistical variations. Each point on the curves is the average of from four to nine values based on measurements reported by the various workers. The subject was standing, sitting, or lying on a support which was vibrated vertically or horizontally.

[22]H. Fletcher and W. A. Munson, "Loudness, Its Definition, Measurement, and Calculation," Journal of the Acoustical Society of America, Vol. 5, (Oct. 1933) pp. 82-108.

[23]Science News—SCIENCE VOL. 119 NO. 3081, January 15, 1954, p. 85.
How Much Jiggling Can a Man Take—DESIGN NEWS, March 1, 1954.

[24]Goldman, D. E., A Review of Subjective Responses to Vibratory Motion of the Human Body in the Frequency Range 1 to 70 Cycles per Second, Report No. 1, Project NM 004001, Naval Medical Research Institute, March 16, 1948.

In addition to the Goldman curves McFarland[25] shows curves prepared by Lippert[26] covering the frequency range of 1 to 200 cps and curves prepared by McFarland[27] covering the frequency range of 10 to 70 cps. The three sets of curves are shown in the same chart and seem to agree within reasonable tolerances.

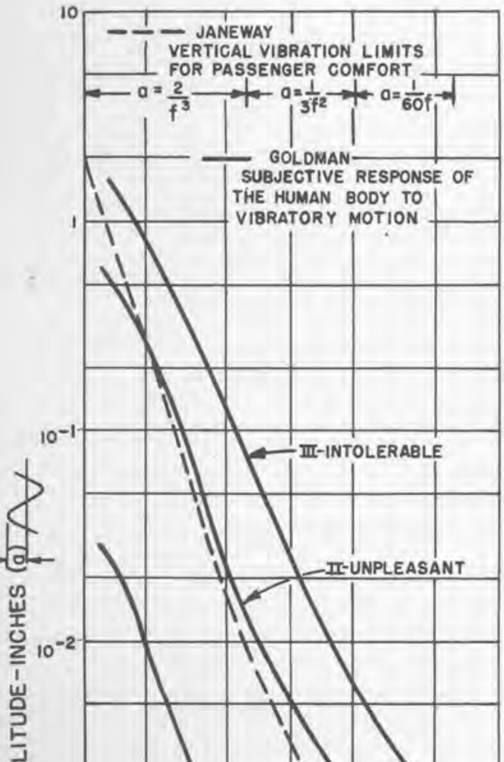


Figure 42. Subjective response of the human body to vibratory motion as a function of frequency.

Using only data collected by Meister[28] and Reiker and Meister[29], Janeway[30] has prepared a chart giving recommended limits of vertical vibration for passenger comfort in automobiles. The data he used also made up a good part of the data used by Goldman but Janeway limited his analysis to data obtained for vertical sinusoidal vibration at a single frequency with subjects standing or sitting on a hard seat. As shown in the dotted curve of Figure 42, the recommended characteristic consists of three simple relationships, each of which covers a portion of the frequency range. In the low frequency range from 1 to 6 cps the recommended limit is a function of the rate of change of acceleration with time (jerk, also called jolt).[31] Mathematically the law is written $af^3=2$ so the maximum comfortable displacement (a) at any frequency between 1 and 6 cps would be 2 divided by the frequency cubed (f^3). Over the frequency range of 6 to 20 cps the recommended limit is a function of the acceleration to which the passenger is subjected. This law is written $af^2=1/3$. From 20 to 60 cps the recommended limit is a function of velocity and the rule is written $af=1/60$.

While it is recognized that more work needs to be done and is in fact being planned by the Navy, as stated earlier, this brief summary has been presented to show that some serious work has been done to determine the response of human beings to vibratory stimuli.

---

[25]McFarland, Ross A., Human Body Size and Capabilities in the Design and Operation of Vehicular Equipment, HARVARD SCHOOL OF PUBLIC HEALTH.

[26]Lippert, S., Human Response to Vertical Vibration, read at S.A.E. National Aeronautical Meeting, October, 1946.

[27]McFarland, Ross A., "Human Factors in Air Transportation," OCCUPATIONAL HEALTH AND SAFETY, New York, McGraw-Hill Book Co.

[28]Meister, F. J., "Sensitivity of Human Beings to Vibration," Forschong (V. D. I. Berlin), May-June, 1935.

[29]Reiker, H. and Meister, F. J., "Sensitivity of Human Beings to Vibration," Forschong (V. D. I. Berlin), February, 1931.

[30]Janeway, R. N., Vertical Vibration Limited for Passenger Comfort in "RIDE AND VIBRATION DATA" a set of reference charts. Society of Automatic Engineers, Inc., Special Publications Department (SP-6).

[31]A proposed definition would make jerk the time rate of change of acceleration. Its unit of measure would be the jolt, 1 jolt equalling 1g per second or 386 inches per second per second per second.

CHAPTER IX

A SIMPLE TWO PICKUP METHOD FOR DETERMINING THE ROTATIONAL VIBRATION OF ROTATING MACHINERY [32]

This measurement technique has been found very useful when vibration analysis must be made on an existing installation of rotating machinery. Two Type 761-P1 vibration pickups and a summing network are required in addition to the Type 761-A Vibration Meter. It is necessary to assume that the engine will behave as a rigid mass and that its center of gravity is equidistant from all four mounting posts.

A simple summing circuit is shown in Figure 43 below. The voltages e_1 and e_2 represent the output signals of the two vibration pickups and the voltage e_0 represents the signal that would be fed into the input of the vibration meter. If the three resistors R are equal then e_0 will be 1/3 of (e_1+e_2). A convenient embodiment of this circuit is sketched in Figure 44. Here only two resistors are shown since the third resistor is in the input circuit of the Type 761-A Vibration Meter. One pickup is connected to input No. 1 and the other pickup is connected to input No. 2. The output of the summing circuit is connected to the input of the Vibration Meter. When S-1 is at 1, 1/3 the output of pickup No. 1 is applied to the input of the vibration meter. When S-1 is set at 2, 1/3 the output of pickup No. 2 is applied to the input of the Vibration Meter and when S-1 is at 3, 1/3 the sum of the outputs from the two pickups is applied to the input of the vibration meter.

[32]This method suggested by Mr. George Kamperman of Bolt, Beranek & Newman, Inc., Cambridge. He has used this technique on numerous occasions with gratifying results.

Figure 43. A simple resistive summing circuit.

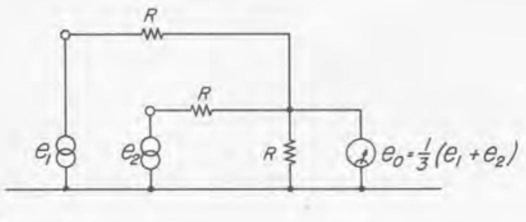
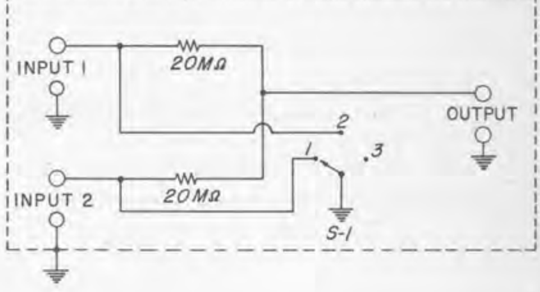


Figure 44. A convenient arrangement of a summing circuit for use at the input of the Type 761-A Vibration Meter.



The top view of a typical engine and its mounting is sketched in outline form in Figure 45. A and B represent the forward engine mounts while C and D represent the rear engine mounts. With the two pickups (oriented for vertical displacement measurement) mounted on the two forward engine mounting brackets, the translational or vertical amplitude is indicated on the vibration meter when the output signals of the two pickups are summed. The rotational mode of vibration is cancelled out. When the outputs of the two pickups are summed 180° out of phase or subtracted, the rotational amplitude of vibration is indicated on the vibration meter and the translational mode of vibration is cancelled out. The output from one pickup can be shifted 180° to perform the subtraction of outputs by mounting the pickup upside down. If desired, the pickup can be left in its normal mounting position and the 180° shift in the phase of its output can be achieved with an electronic phase inventer. By making the set of measurements outlined above on all pairs of mounting brackets (A,B—C,D—A,D—B,C) the amplitude of any rotational or rocking motion about the axes a-a' or b-b' can easily be sorted out from the direct vertical or translational motion of the engine.

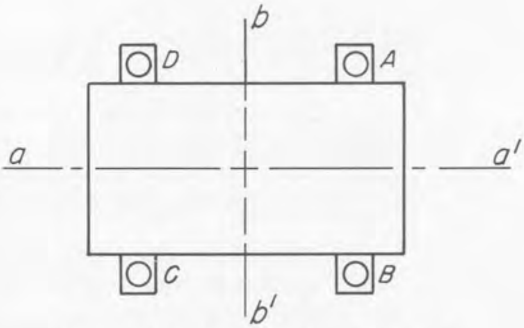


Figure 45. Outline of engine and mounting (top view).

APPENDIX I

The decibel tables in this booklet offer a convenient means of converting decibel vibration readings obtained with the sound-level meter and vibration pickup into displacement in inches, velocity in inches per second, and acceleration in inches per second per second.

Each control box nameplate is inscribed with a conversion table which applies to that control box when used with the particular pickup and sound-level meter indicated on the nameplate. The conversion figures appearing on the nameplate of the control box are:

Displacement	120 db = 1 in. rms
Velocity	90 db = 1 in. per second
Acceleration	40 db = 1 in. per second per second rms

N.B. For Type 759-P36 Control Boxes manufactured before 1955, the actual conversion figures for a given control box when used with a specific vibration pickup and sound-level meter will probably differ slightly from the above. When this is true, substitute actual conversion figures for the values used below to obtain correct conversion.

TO CONVERT DB SOUND-LEVEL METER READINGS INTO RMS AMPLITUDE IN INCHES

1. Note decibel readings of sound-level meter when vibration pickup is in contact with vibrating surface and control box switch is set at DISPLACEMENT.

2. If reading for Step 1 is below 120 db: Subtract +20 db successively from (120 minus db reading) until the remainder falls within the range of Table I of decibel tables. RMS amplitude in inches is then found by multiplying the voltage ratio (left-hand column) corresponding to the db remainder by 0.1 for each time you subtracted 20 db. Figures obtained are expressed directly in inches RMS amplitude.

If reading for Step 1 is above 120 db (maximum 140 db): Subtract +20 db successively from (db reading minus 120 db) until the remainder falls within the range of Table I. The RMS amplitude in inches is then found by multiplying the voltage ratio (right-hand voltage ratio column) corresponding to the db remainder by 10 for each time you subtracted 20 db. Figures obtained are expressed directly in inches RMS amplitude.

TO CONVERT DB SOUND-LEVEL METER READINGS INTO RMS VELOCITY IN INCHES PER SECOND

1. Note db reading of sound-level meter with vibration pickup in contact with vibrating surface and control box switch set at VELOCITY.

2. If reading for Step 1 is below 90 db: Subtract +20 db successively from (90 minus db reading) until the remainder falls within the range of Table I of decibel tables. RMS velocity in inches per second is then found by multiplying the voltage ratio (left-hand voltage ratio column) corresponding to the db remainder by 0.1 for each time you

subtracted 20 db. Figures obtained are directly RMS velocity in inches per second.

If reading for Step 1 is above 90 db: Subtract +20 db successively from (db reading minus 90) until the remainder falls within the range of Table I. The RMS velocity in inches per second is then found by multiplying the voltage ratio (right-hand voltage ratio column) corresponding to db remainder by 10 for each time you subtracted 20 db. Figures obtained will be directly the RMS velocity in inches per second.

TO CONVERT DB SOUND-LEVEL METER READINGS
INTO RMS ACCELERATION IN INCHES PER SECOND PER SECOND

1. Note db reading of sound-level meter with vibration pickup in contact with vibrating surface and control box switch set at ACCELERATION.

2. If reading of Step 1 is below 40 db: Subtract +20 db successively from (40 minus db reading) until the remainder falls within the range of Table I. The RMS acceleration in inches per second per second is then obtained by mulitplying the voltage ratio (left-hand ratio column) corresponding to the db remainder by 0.1 for each time you subtracted 20 db. Figures obtained are then directly the RMS acceleration expressed in inches per second per second.

If reading for Step 1 is above 40 db (maximum 140 db): Subtract +20 db successively from (db reading minus 40) until the remainder falls within the range of Table I. The RMS acceleration in inches per second per second is then found by multiplying the voltage ratio (right-hand voltage ratio column) corresponding to the db remainder by 10 for each time you subtracted 20 db. Figures obtained are then RMS acceleration expressed in inches per second per second.

EXAMPLE

With the vibration pickup placed in contact with some vibrating surface and the control box switch, let us say, on DISPLACEMENT, a reading of 54 db is obtained. Then, following outlined procedure:

1. Db reading = 54 db.
2. 120 - 54 = 66 db.
   66 - (+20) - (+20) - (+20) = 6 db remainder.

Voltage ratios corresponding to 6 db (left-hand column) equal 0.5012; 20 db was subtracted from 66 db three times, so that 0.5012 should be multiplied by 0.1 three times.

Result = 0.0005012 or (to 2 significant figures) 0.00050 inches RMS amplitude.

Like procedure should be followed for the calculation of velocity or acceleration.

DECIBEL CONVERSION TABLES

It is convenient in measurements and calculations on communications systems to express the ratio between any two amounts of electric or acoustic power in units on a logarithmic scale. The *decibel* (1/10th of the *bel*) on the briggsian or base-10 scale and the *neper* on the napierian or base-*e* scale are in almost universal use for this purpose.

Since voltage and current are related to power by impedance, both the *decibel* and the *neper* can be used to express voltage and current ratios, if care is taken to account for the impedances associated with them. In a similar manner the corresponding acoustical quantities can be compared.

Table I and Table II on the following pages have been prepared to facilitate making conversions in either direction between the number of *decibels* and the corresponding power, voltage, and current ratios. Both tables can also be used for *nepers* and the *mile of standard cable* by applying the conversion factors from the table on the opposite page.

Decibel — The number of decibels N_{db} corresponding to the ratio between two amounts of power P_1 and P_2 is

$$N_{db} = 10 \log_{10} \frac{P_1}{P_2} \quad (1)$$

When two voltages E_1 and E_2 or two currents I_1 and I_2 operate in identical impedances,

$$N_{db} = 20 \log_{10} \frac{E_1}{E_2} \quad (2)$$

and

$$N_{db} = 20 \log_{10} \frac{I_1}{I_2} \quad (3)$$

If E_1 and E_2 or I_1 and I_2 operate in unequal impedances,

$$N_{db} = 20 \log_{10} \frac{E_1}{E_2} + 10 \log_{10} \frac{Z_2}{Z_1} + 10 \log_{10} \frac{k_1}{k_2} \quad (4)$$

and

$$N_{db} = 20 \log_{10} \frac{I_1}{I_2} + 10 \log_{10} \frac{Z_1}{Z_2} + 10 \log_{10} \frac{k_1}{k_2} \quad (5)$$

where Z_1 and Z_2 are the absolute magnitudes of the corresponding impedances and k_1 and k_2 are the values of power factor for the impedances. E_1, E_2, I_1, and I_2 are also the absolute magnitudes of the corresponding quantities. Note that Table I and Table II can be used to evaluate the impedance and power factor terms, since both are similar to the expression for power ratio, equation (1).

Neper — The number of nepers N_{nep} corresponding to a power ratio $\frac{P_1}{P_2}$ is

$$N_{nep} = \frac{1}{2} \log_e \frac{P_1}{P_2} \quad (6)$$

For voltage ratios $\frac{E_1}{E_2}$ or current ratios $\frac{I_1}{I_2}$ working in identical impedances,

$$N_{nep} = \log_e \frac{E_1}{E_2} \quad (7)$$

and

$$N_{nep} = \log_e \frac{I_1}{I_2}$$

When E_1 and E_2 or I_1 and I_2 operate in unequal impedances,

$$N_{nep} = \log_e \frac{E_1}{E_2} + \frac{1}{2} \log_e \frac{Z_2}{Z_1} + \frac{1}{2} \log_e \frac{k_1}{k_2} \quad (8)$$

and

$$N_{nep} = \log_e \frac{I_1}{I_2} + \frac{1}{2} \log_e \frac{Z_1}{Z_2} + \frac{1}{2} \log_e \frac{k_1}{k_2} \quad (9)$$

where Z_1 and Z_2 and k_1 and k_2 are as in equations (4) and (5).

RELATIONS BETWEEN DECIBELS, NEPERS, AND MILES OF STANDARD CABLE

Multiply	*By*	*To Find*
decibels......	.1151	nepers
decibels......	1.056	miles of standard cable
miles of standard cable	.947	decibels
miles of standard cable	.109	nepers
nepers.......	8.686	decibels
nepers.......	9.175	miles of standard cable

TO FIND VALUES OUTSIDE THE RANGE OF CONVERSION TABLES

Values outside the range of either Table I or Table II on the following pages can be readily found with the help of the following simple rules:

TABLE I: DECIBELS TO VOLTAGE AND POWER RATIOS

Number of decibels positive (+): Subtract +20 decibels successively from the given number of decibels until the remainder falls within range of Table I. *To find the voltage ratio*, multiply the corresponding value from the right-hand voltage-ratio column by 10 for each time you subtracted 20 db. *To find the power ratio*, multiply the corresponding value from the right-hand power-ratio column by 100 for each time you subtracted 20 db.

Example — *Given:* 49.2 db.
49.2 db − 20 db − 20 db = 9.2 db
Voltage ratio: 9.2 db → 2.884
2.884 × 10 × 10 = 288.4 → 49.2 db
Power ratio: 9.2 db → 8.318
8.318 × 100 × 100 = 83180 → 49.2 db

Number of decibels negative (−): Add +20 decibels successively to the given number of decibels until the sum falls within the range of Table I. *For the voltage ratio*, divide the value from the left-hand voltage-ratio column by 10 for each time you added 20 db. *For the power ratio*, divide the value from the left-hand power-ratio column by 100 for each time you added 20 db.

Example — *Given:* −49.2 db
−49.2 db + 20 db + 20 db = −9.2 db
Voltage ratio: −9.2 db → .3467
.3467 × 1/10 × 1/10 = .003467 → −49.2 db
Power ratio: −9.2 db → .1202
.1202 × 1/100 × 1/100 = .00001202 → −49.2 db

TABLE II: VOLTAGE RATIOS TO DECIBELS

For ratios smaller than those in table—Multiply the given ratio by 10 successively until the product can be found in the table. From the number of decibels thus found, subtract +20 decibels for each time you multiplied by 10.

Example—*Given:* Voltage ratio = .0131
.0131 × 10 × 10 = 1.31

From Table II, 1.31 → 2.345 db
2.345 db − 20 db − 20 db = −37.655 db

For ratios greater than those in table—Divide the given ratio by 10 successively until the remainder can be found in the table. To the number of decibels thus found, add +20 db for each time you divided by 10.

Example—*Given:* Voltage ratio = 712
712 × 1/10 × 1/10 = 7.12

From Table II, 7.12 → 17.050 db
17.050 db + 20 db + 20 db = 57.050 db

APPENDIX

TABLE I

GIVEN: Decibels — **TO FIND: Power and {Voltage / Current} Ratios**

TO ACCOUNT FOR THE SIGN OF THE DECIBEL

For positive (+) values of the decibel—Both voltage and power ratios are greater than unity. Use the two right-hand columns.

For negative (−) values of the decibel—Both voltage and power ratios are less than unity. Use the two left-hand columns.

Example—*Given:* ± 9.1 db. *Find:*

	Power Ratio	*Voltage Ratio*
+9.1 db	8.128	2.851
−9.1 db	0.1230	0.3508

← −db+ →

Voltage Ratio	*Power Ratio*	*db*	*Voltage Ratio*	*Power Ratio*
1.0000	1.0000	0	1.000	1.000
.9886	.9772	.1	1.012	1.023
.9772	.9550	.2	1.023	1.047
.9661	.9333	.3	1.035	1.072
.9550	.9120	.4	1.047	1.096
.9441	.8913	.5	1.059	1.122
.9333	.8710	.6	1.072	1.148
.9226	.8511	.7	1.084	1.175
.9120	.8318	.8	1.096	1.202
.9016	.8128	.9	1.109	1.230
.8913	.7943	1.0	1.122	1.259
.8810	.7762	1.1	1.135	1.288
.8710	.7586	1.2	1.148	1.318
.8610	.7413	1.3	1.161	1.349
.8511	.7244	1.4	1.175	1.380
.8414	.7079	1.5	1.189	1.413
.8318	.6918	1.6	1.202	1.445
.8222	.6761	1.7	1.216	1.479
.8128	.6607	1.8	1.230	1.514
.8035	.6457	1.9	1.245	1.549
.7943	.6310	2.0	1.259	1.585
.7852	.6166	2.1	1.274	1.622
.7762	.6026	2.2	1.288	1.660
.7674	.5888	2.3	1.303	1.698
.7586	.5754	2.4	1.318	1.738
.7499	.5623	2.5	1.334	1.778
.7413	.5495	2.6	1.349	1.820
.7328	.5370	2.7	1.365	1.862
.7244	.5248	2.8	1.380	1.905
.7161	.5129	2.9	1.396	1.950
.7079	.5012	3.0	1.413	1.995
.6998	.4898	3.1	1.429	2.042
.6918	.4786	3.2	1.445	2.089
.6839	.4677	3.3	1.462	2.138
.6761	.4571	3.4	1.479	2.188
.6683	.4467	3.5	1.496	2.239
.6607	.4365	3.6	1.514	2.291
.6531	.4266	3.7	1.531	2.344
.6457	.4169	3.8	1.549	2.399
.6383	.4074	3.9	1.567	2.455
.6310	.3981	4.0	1.585	2.512
.6237	.3890	4.1	1.603	2.570
.6166	.3802	4.2	1.622	2.630
.6095	.3715	4.3	1.641	2.692
.6026	.3631	4.4	1.660	2.754
.5957	.3548	4.5	1.679	2.818
.5888	.3467	4.6	1.698	2.884
.5821	.3388	4.7	1.718	2.951
.5754	.3311	4.8	1.738	3.020
.5689	.3236	4.9	1.758	3.090

← −db+ →

Voltage Ratio	*Power Ratio*	*db*	*Voltage Ratio*	*Power Ratio*
.5623	.3162	5.0	1.778	3.162
.5559	.3090	5.1	1.799	3.236
.5495	.3020	5.2	1.820	3.311
.5433	.2951	5.3	1.841	3.388
.5370	.2884	5.4	1.862	3.467
.5309	.2818	5.5	1.884	3.548
.5248	.2754	5.6	1.905	3.631
.5188	.2692	5.7	1.928	3.715
.5129	.2630	5.8	1.950	3.802
.5070	.2570	5.9	1.972	3.890
.5012	.2512	6.0	1.995	3.981
.4955	.2455	6.1	2.018	4.074
.4898	.2399	6.2	2.042	4.169
.4842	.2344	6.3	2.065	4.266
.4786	.2291	6.4	2.089	4.365
.4732	.2239	6.5	2.113	4.467
.4677	.2188	6.6	2.138	4.571
.4624	.2138	6.7	2.163	4.677
.4571	.2089	6.8	2.188	4.786
.4519	.2042	6.9	2.213	4.898
.4467	.1995	7.0	2.239	5.012
.4416	.1950	7.1	2.265	5.129
.4365	.1905	7.2	2.291	5.248
.4315	.1862	7.3	2.317	5.370
.4266	.1820	7.4	2.344	5.495
.4217	.1778	7.5	2.371	5.623
.4169	.1738	7.6	2.399	5.754
.4121	.1698	7.7	2.427	5.888
.4074	.1660	7.8	2.455	6.026
.4027	.1622	7.9	2.483	6.166
.3981	.1585	8.0	2.512	6.310
.3936	.1549	8.1	2.541	6.457
.3890	.1514	8.2	2.570	6.607
.3846	.1479	8.3	2.600	6.761
.3802	.1445	8.4	2.630	6.918
.3758	.1413	8.5	2.661	7.079
.3715	.1380	8.6	2.692	7.244
.3673	.1349	8.7	2.723	7.413
.3631	.1318	8.8	2.754	7.586
.3589	.1288	8.9	2.786	7.762
.3548	.1259	9.0	2.818	7.943
.3508	.1230	9.1	2.851	8.128
.3467	.1202	9.2	2.884	8.318
.3428	.1175	9.3	2.917	8.511
.3388	.1148	9.4	2.951	8.710
.3350	.1122	9.5	2.985	8.913
.3311	.1096	9.6	3.020	9.120
.3273	.1072	9.7	3.055	9.333
.3236	.1047	9.8	3.090	9.550
.3199	.1023	9.9	3.126	9.772

TABLE I (continued)

Voltage Ratio (−db)	Power Ratio (−db)	db	Voltage Ratio (+db)	Power Ratio (+db)
.3162	.1000	10.0	3.162	10.000
.3126	.09772	10.1	3.199	10.23
.3090	.09550	10.2	3.236	10.47
.3055	.09333	10.3	3.273	10.72
.3020	.09120	10.4	3.311	10.96
.2985	.08913	10.5	3.350	11.22
.2951	.08710	10.6	3.388	11.48
.2917	.08511	10.7	3.428	11.75
.2884	.08318	10.8	3.467	12.02
.2851	.08128	10.9	3.508	12.30
.2818	.07943	11.0	3.548	12.59
.2786	.07762	11.1	3.589	12.88
.2754	.07586	11.2	3.631	13.18
.2723	.07413	11.3	3.673	13.49
.2692	.07244	11.4	3.715	13.80
.2661	.07079	11.5	3.758	14.13
.2630	.06918	11.6	3.802	14.45
.2600	.06761	11.7	3.846	14.79
.2570	.06607	11.8	3.890	15.14
.2541	.06457	11.9	3.936	15.49
.2512	.06310	12.0	3.981	15.85
.2483	.06166	12.1	4.027	16.22
.2455	.06026	12.2	4.074	16.60
.2427	.05888	12.3	4.121	16.98
.2399	.05754	12.4	4.169	17.38
.2371	.05623	12.5	4.217	17.78
.2344	.05495	12.6	4.266	18.20
.2317	.05370	12.7	4.315	18.62
.2291	.05248	12.8	4.365	19.05
.2265	.05129	12.9	4.416	19.50
.2239	.05012	13.0	4.467	19.95
.2213	.04898	13.1	4.519	20.42
.2188	.04786	13.2	4.571	20.89
.2163	.04677	13.3	4.624	21.38
.2138	.04571	13.4	4.677	21.88
.2113	.04467	13.5	4.732	22.39
.2089	.04365	13.6	4.786	22.91
.2065	.04266	13.7	4.842	23.44
.2042	.04169	13.8	4.898	23.99
.2018	.04074	13.9	4.955	24.55
.1995	.03981	14.0	5.012	25.12
.1972	.03890	14.1	5.070	25.70
.1950	.03802	14.2	5.129	26.30
.1928	.03715	14.3	5.188	26.92
.1905	.03631	14.4	5.248	27.54
.1884	.03548	14.5	5.309	28.18
.1862	.03467	14.6	5.370	28.84
.1841	.03388	14.7	5.433	29.51
.1820	.03311	14.8	5.495	30.20
.1799	.03236	14.9	5.559	30.90
.1778	.03162	15.0	5.623	31.62
.1758	.03090	15.1	5.689	32.36
.1738	.03020	15.2	5.754	33.11
.1718	.02951	15.3	5.821	33.88
.1698	.02884	15.4	5.888	34.67
.1679	.02818	15.5	5.957	35.48
.1660	.02754	15.6	6.026	36.31
.1641	.02692	15.7	6.095	37.15
.1622	.02630	15.8	6.166	38.02
.1603	.02570	15.9	6.237	38.90
.1585	.02512	16.0	6.310	39.81
.1567	.02455	16.1	6.383	40.74
.1549	.02399	16.2	6.457	41.69
.1531	.02344	16.3	6.531	42.66
.1514	.02291	16.4	6.607	43.65
.1496	.02239	16.5	6.683	44.67
.1479	.02188	16.6	6.761	45.71
.1462	.02138	16.7	6.839	46.77
.1445	.02089	16.8	6.918	47.86
.1429	.02042	16.9	6.998	48.98
.1413	.01995	17.0	7.079	50.12
.1396	.01950	17.1	7.161	51.29
.1380	.01905	17.2	7.244	52.48
.1365	.01862	17.3	7.328	53.70
.1349	.01820	17.4	7.413	54.95
.1334	.01778	17.5	7.499	56.23
.1318	.01738	17.6	7.586	57.54
.1303	.01698	17.7	7.674	58.88
.1288	.01660	17.8	7.762	60.26
.1274	.01622	17.9	7.852	61.66
.1259	.01585	18.0	7.943	63.10
.1245	.01549	18.1	8.035	64.57
.1230	.01514	18.2	8.128	66.07
.1216	.01479	18.3	8.222	67.61
.1202	.01445	18.4	8.318	69.18
.1189	.01413	18.5	8.414	70.79
.1175	.01380	18.6	8.511	72.44
.1161	.01349	18.7	8.610	74.13
.1148	.01318	18.8	8.710	75.86
.1135	.01288	18.9	8.811	77.62
.1122	.01259	19.0	8.913	79.43
.1109	.01230	19.1	9.016	81.28
.1096	.01202	19.2	9.120	83.18
.1084	.01175	19.3	9.226	85.11
.1072	.01148	19.4	9.333	87.10
.1059	.01122	19.5	9.441	89.13
.1047	.01096	19.6	9.550	91.20
.1035	.01072	19.7	9.661	93.33
.1023	.01047	19.8	9.772	95.50
.1012	.01023	19.9	9.886	97.72
.1000	.01000	20.0	10.000	100.00

Voltage Ratio (−db)	Power Ratio (−db)	db	Voltage Ratio (+db)	Power Ratio (+db)
3.162×10^{-1}	10^{-1}	10	3.162	10
10^{-1}	10^{-2}	20	10	10^{2}
3.162×10^{-2}	10^{-3}	30	3.162×10	10^{3}
10^{-2}	10^{-4}	40	10^{2}	10^{4}
3.162×10^{-3}	10^{-5}	50	3.162×10^{2}	10^{5}
10^{-3}	10^{-6}	60	10^{3}	10^{6}
3.162×10^{-4}	10^{-7}	70	3.162×10^{3}	10^{7}
10^{-4}	10^{-8}	80	10^{4}	10^{8}
3.162×10^{-5}	10^{-9}	90	3.162×10^{4}	10^{9}
10^{-5}	10^{-10}	100	10^{5}	10^{10}

To find decibel values outside the range of this table, see page 47

TABLE II

GIVEN: {Voltage / Current} Ratio — **TO FIND: Decibels**

POWER RATIOS

To find the number of decibels corresponding to a given power ratio—Assume the given power ratio to be a voltage ratio and find the corresponding number of decibels from the table. The desired result is exactly one-half of the number of decibels thus found.

Example—*Given:* a power ratio of 3.41.
Find: 3.41 in the table:

3.41→10.655 db (voltage)
10.655 db × ½ = 5.328 db (power)

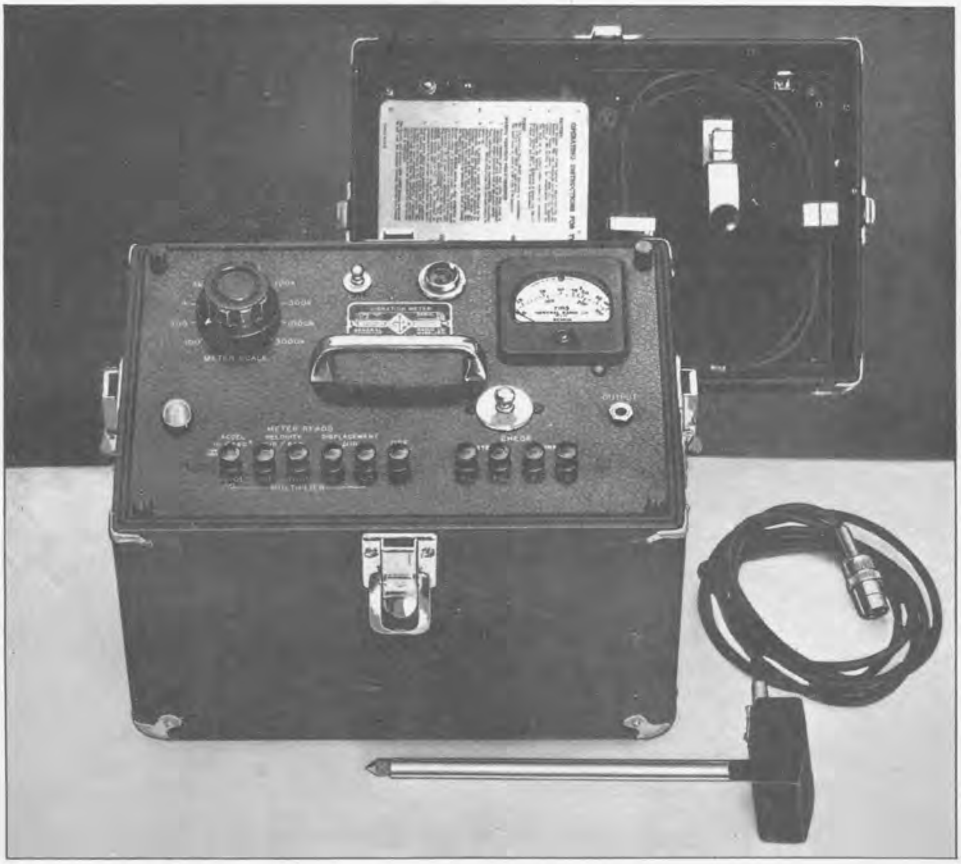
Voltage Ratio	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
1.0	.000	.086	.172	.257	.341	.424	.506	.588	.668	.749
1.1	.828	.906	.984	1.062	1.138	1.214	1.289	1.364	1.438	1.511
1.2	1.584	1.656	1.727	1.798	1.868	1.938	2.007	2.076	2.144	2.212
1.3	2.279	2.345	2.411	2.477	2.542	2.607	2.671	2.734	2.798	2.860
1.4	2.923	2.984	3.046	3.107	3.167	3.227	3.287	3.346	3.405	3.464
1.5	3.522	3.580	3.637	3.694	3.750	3.807	3.862	3.918	3.973	4.028
1.6	4.082	4.137	4.190	4.244	4.297	4.350	4.402	4.454	4.506	4.558
1.7	4.609	4.660	4.711	4.761	4.811	4.861	4.910	4.959	5.008	5.057
1.8	5.105	5.154	5.201	5.249	5.296	5.343	5.390	5.437	5.483	5.529
1.9	5.575	5.621	5.666	5.711	5.756	5.801	5.845	5.889	5.933	5.977
2.0	6.021	6.064	6.107	6.150	6.193	6.235	6.277	6.319	6.361	6.403
2.1	6.444	6.486	6.527	6.568	6.608	6.649	6.689	6.729	6.769	6.809
2.2	6.848	6.888	6.927	6.966	7.008	7.044	7.082	7.121	7.159	7.197
2.3	7.235	7.272	7.310	7.347	7.384	7.421	7.458	7.495	7.532	7.568
2.4	7.604	7.640	7.676	7.712	7.748	7.783	7.819	7.854	7.889	7.924
2.5	7.959	7.993	8.028	8.062	8.097	8.131	8.165	8.199	8.232	8.266
2.6	8.299	8.333	8.366	8.399	8.432	8.465	8.498	8.530	8.563	8.595
2.7	8.627	8.659	8.691	8.723	8.755	8.787	8.818	8.850	8.881	8.912
2.8	8.943	8.974	9.005	9.036	9.066	9.097	9.127	9.158	9.188	9.218
2.9	9.248	9.278	9.308	9.337	9.367	9.396	9.426	9.455	9.484	9.513
3.0	9.542	9.571	9.600	9.629	9.657	9.686	9.714	9.743	9.771	9.799
3.1	9.827	9.855	9.883	9.911	9.939	9.966	9.994	10.021	10.049	10.076
3.2	10.103	10.130	10.157	10.184	10.211	10.238	10.264	10.291	10.317	10.344
3.3	10.370	10.397	10.423	10.449	10.475	10.501	10.527	10.553	10.578	10.604
3.4	10.630	10.655	10.681	10.706	10.731	10.756	10.782	10.807	10.832	10.857
3.5	10.881	10.906	10.931	10.955	10.980	11.005	11.029	11.053	11.078	11.102
3.6	11.126	11.150	11.174	11.198	11.222	11.246	11.270	11.293	11.317	11.341
3.7	11.364	11.387	11.411	11.434	11.457	11.481	11.504	11.527	11.550	11.573
3.8	11.596	11.618	11.641	11.664	11.687	11.709	11.732	11.754	11.777	11.799
3.9	11.821	11.844	11.866	11.888	11.910	11.932	11.954	11.976	11.998	12.019
4.0	12.041	12.063	12.085	12.106	12.128	12.149	12.171	12.192	12.213	12.234
4.1	12.256	12.277	12.298	12.319	12.340	12.361	12.382	12.403	12.424	12.444
4.2	12.465	12.486	12.506	12.527	12.547	12.568	12.588	12.609	12.629	12.649
4.3	12.669	12.690	12.710	12.730	12.750	12.770	12.790	12.810	12.829	12.849
4.4	12.869	12.889	12.908	12.928	12.948	12.967	12.987	13.006	13.026	13.045
4.5	13.064	13.084	13.103	13.122	13.141	13.160	13.179	13.198	13.217	13.236
4.6	13.255	13.274	13.293	13.312	13.330	13.349	13.368	13.386	13.405	13.423
4.7	13.442	13.460	13.479	13.497	13.516	13.534	13.552	13.570	13.589	13.607
4.8	13.625	13.643	13.661	13.679	13.697	13.715	13.733	13.751	13.768	13.786
4.9	13.804	13.822	13.839	13.857	13.875	13.892	13.910	13.927	13.945	13.962
5.0	13.979	13.997	14.014	14.031	14.049	14.066	14.083	14.100	14.117	14.134
5.1	14.151	14.168	14.185	14.202	14.219	14.236	14.253	14.270	14.287	14.303
5.2	14.320	14.337	14.353	14.370	14.387	14.403	14.420	14.436	14.453	14.469
5.3	14.486	14.502	14.518	14.535	14.551	14.567	14.583	14.599	14.616	14.632
5.4	14.648	14.664	14.680	14.696	14.712	14.728	14.744	14.760	14.776	14.791
5.5	14.807	14.823	14.839	14.855	14.870	14.886	14.902	14.917	14.933	14.948
5.6	14.964	14.979	14.995	15.010	15.026	15.041	15.056	15.072	15.087	15.102
5.7	15.117	15.133	15.148	15.163	15.178	15.193	15.208	15.224	15.239	15.254
5.8	15.269	15.284	15.298	15.313	15.328	15.343	15.358	15.373	15.388	15.402
5.9	15.417	15.432	15.446	15.461	15.476	15.490	15.505	15.519	15.534	15.549

TABLE II (continued)

Voltage Ratio	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
6.0	**15.563**	**15.577**	**15.592**	**15.606**	**15.621**	**15.635**	**15.649**	**15.664**	**15.678**	**15.692**
6.1	15.707	15.721	15.735	15.749	15.763	15.778	15.792	15.806	15.820	15.834
6.2	15.848	15.862	15.876	15.890	15.904	15.918	15.931	15.945	15.959	15.973
6.3	15.987	16.001	16.014	16.028	16.042	16.055	16.069	16.083	16.096	16.110
6.4	16.124	16.137	16.151	16.164	16.178	16.191	16.205	16.218	16.232	16.245
6.5	16.258	16.272	16.285	16.298	16.312	16.325	16.338	16.351	16.365	16.378
6.6	16.391	16.404	16.417	16.430	16.443	16.456	16.469	16.483	16.496	16.509
6.7	16.521	16.534	16.547	16.560	16.573	16.586	16.599	16.612	16.625	16.637
6.8	16.650	16.663	16.676	16.688	16.701	16.714	16.726	16.739	16.752	16.764
6.9	16.777	16.790	16.802	16.815	16.827	16.840	16.852	16.865	16.877	16.890
7.0	**16.902**	**16.914**	**16.927**	**16.939**	**16.951**	**16.964**	**16.976**	**16.988**	**17.001**	**17.013**
7.1	17.025	17.037	17.050	17.062	17.074	17.086	17.098	17.110	17.122	17.135
7.2	17.147	17.159	17.171	17.183	17.195	17.207	17.219	17.231	17.243	17.255
7.3	17.266	17.278	17.290	17.302	17.314	17.326	17.338	17.349	17.361	17.373
7.4	17.385	17.396	17.408	17.420	17.431	17.443	17.455	17.466	17.478	17.490
7.5	17.501	17.513	17.524	17.536	17.547	17.559	17.570	17.582	17.593	17.605
7.6	17.616	17.628	17.639	17.650	17.662	17.673	17.685	17.696	17.707	17.719
7.7	17.730	17.741	17.752	17.764	17.775	17.786	17.797	17.808	17.820	17.831
7.8	17.842	17.853	17.864	17.875	17.886	17.897	17.908	17.919	17.931	17.942
7.9	17.953	17.964	17.975	17.985	17.996	18.007	18.018	18.029	18.040	18.051
8.0	**18.062**	**18.073**	**18.083**	**18.094**	**18.105**	**18.116**	**18.127**	**18.137**	**18.148**	**18.159**
8.1	18.170	18.180	18.191	18.202	18.212	18.223	18.234	18.244	18.255	18.266
8.2	18.276	18.287	18.297	18.308	18.319	18.329	18.340	18.350	18.361	18.371
8.3	18.382	18.392	18.402	18.413	18.423	18.434	18.444	18.455	18.465	18.475
8.4	18.486	18.496	18.506	18.517	18.527	18.537	18.547	18.558	18.568	18.578
8.5	18.588	18.599	18.609	18.619	18.629	18.639	18.649	18.660	18.670	18.680
8.6	18.690	18.700	18.710	18.720	18.730	18.740	18.750	18.760	18.770	18.780
8.7	18.790	18.800	18.810	18.820	18.830	18.840	18.850	18.860	18.870	18.880
8.8	18.890	18.900	18.909	18.919	18.929	18.939	18.949	18.958	18.968	18.978
8.9	18.988	18.998	19.007	19.017	19.027	19.036	19.046	19.056	19.066	19.075
9.0	**19.085**	**19.094**	**19.104**	**19.114**	**19.123**	**19.133**	**19.143**	**19.152**	**19.162**	**19.171**
9.1	19.181	19.190	19.200	19.209	19.219	19.228	19.238	19.247	19.257	19.266
9.2	19.276	19.285	19.295	19.304	19.313	19.323	19.332	19.342	19.351	19.360
9.3	19.370	19.379	19.388	19.398	19.407	19.416	19.426	19.435	19.444	19.453
9.4	19.463	19.472	19.481	19.490	19.499	19.509	19.518	19.527	19.536	19.545
9.5	19.554	19.564	19.573	19.582	19.591	19.600	19.609	19.618	19.627	19.636
9.6	19.645	19.654	19.664	19.673	19.682	19.691	19.700	19.709	19.718	19.726
9.7	19.735	19.744	19.753	19.762	19.771	19.780	19.789	19.798	19.807	19.816
9.8	19.825	19.833	19.842	19.851	19.860	19.869	19.878	19.886	19.895	19.904
9.9	19.913	19.921	19.930	19.939	19.948	19.956	19.965	19.974	19.983	19.991

Voltage Ratio	0	1	2	3	4	5	6	7	8	9
10	**20.000**	**20.828**	**21.584**	**22.279**	**22.923**	**23.522**	**24.082**	**24.609**	**25.105**	**25.575**
20	26.021	26.444	26.848	27.235	27.604	27.959	28.299	28.627	28.943	29.248
30	29.542	29.827	30.103	30.370	30.630	30.881	31.126	31.364	31.596	31.821
40	32.041	32.256	32.465	32.669	32.869	33.064	33.255	33.442	33.625	33.804
50	33.979	34.151	34.320	34.486	34.648	34.807	34.964	35.117	35.269	35.417
60	35.563	35.707	35.848	35.987	36.124	36.258	36.391	36.521	36.650	36.777
70	36.902	37.025	37.147	37.266	37.385	37.501	37.616	37.730	37.842	37.953
80	38.062	38.170	38.276	38.382	38.486	38.588	38.690	38.790	38.890	38.988
90	39.085	39.181	39.276	39.370	39.463	39.554	39.645	39.735	39.825	39.913
100	**40.000**	—	—	—	—	—	—	—	—	—

To find ratios outside the range of this table, see page 47



TYPE 761-A VIBRATION METER

USES: Vibrations in machines and structures can be measured quickly and easily with this instrument. For the manufacturer of machinery and equipment, the TYPE 761-A Vibration Meter is extremely useful in research, design, and production testing. Maintenance engineers will find it useful for checking the operating condition of bearings, gear trains, and other mechanisms. Excessive vibrations due to improper adjustment or to structural resonances can be located and measured.

Its excellent low-frequency response permits the study of the operation of belt drives and of the effectiveness of mountings designed to reduce vibrations in adjacent structures.

A frequency analysis of the measured vibration can be made with the TYPE 762-B Vibration Analyzeı.

DESCRIPTION: The TYPE 761-A Vibration Meter consists essentially of a vibration pickup, adjustable attenuator, an amplifier, and a direct-reading indicating meter. The pickup is of the inertia-operated crystal type, which delivers a voltage proportional to the acceleration of the vibratory motion. An integrating network converts this output, when desired, to a voltage proportional to velocity or to displacement. The type of response is selected by push-button switches.

The basic units in which the instrument is calibrated are inches and seconds, and calibrations are in root-mean-square values.

FEATURES: ➤ Portable and self-contained.

➤ Simple to operate.

➤ Direct reading.

➤ Reads three response characteristics, acceleration, velocity, and displacement.

➤ Low-frequency response down to 2 cycles per second (120 per minute).

➤ Independent output system for panel meter and output terminals.

➤ Semi-logarithmic meter scale permits wide range of measurement with a single multiplier setting.

➤ Particularly well adapted to the measurement of machinery vibrations.

SPECIFICATIONS

RANGES: The vibration meter is direct-reading in the units shown in the range table below.

Vibration Quantity	*Range*
Displacement	16 micro-inches to 30 inches, rms.
Velocity	160 micro-inches per second to 300 inches per second, rms.
Acceleration	0.160 inch per second per second to 3900 inches per second per second, rms.

RESPONSE CHARACTERISTICS: The response follows theoretical curves of the quantity measured, vs. frequency within the following tolerances.

Quantity	*Range*	*Tolerance*	*Frequency Range*	
Acceleration	0.160 in./sec/sec to 3900 in./sec/sec	±10%	4 to 500 cps	Down 25% at 2 cps
Velocity	1600 μin./sec to 300 in./sec	±10%	5 to 500 cps	Down 40% at 2 cps
Velocity	Below 1600 μin./sec	±15%	20 to 500 cps	Down 25% at 10 cps
Displacement	160 μin. to 30 in.	±10%	10 to 500 cps	Down 50% at 2 cps
Displacement	Below 160 μin.	±15%	20 to 500 cps	Down 25% at 10 cps

Above 500 cps the error increases and may reach ±30% at 1000 cps. This is caused by the differences in response of individual pickups near resonance.

Pickup Unit: Inertia-operated, Rochelle-salt-crystal type. Non-linearity occurs at 10 g or 3900 inches per second per second. Point and ball tips and an 8-inch extension rod are supplied.

Meter: Scale reads directly in the quantity being measured — root-mean-square micro-inches for displacement, root-mean-square micro-inches per second for velocity, and root-mean-square inches per second per second for acceleration.

Attenuators: A 10-step attenuator changes the meter scale calibration over a range of 30,000 to 1. Additional multipliers indicate the correct units of measurement and multiplying factors for each response characteristic.

Calibration: Connection to any a-c power line makes it possible to check the over-all calibration excluding pickup.

Terminals: A jack is provided on the panel for plugging in a pair of head telephones in order to listen to the vibrations being measured, for connecting the Type 762-B Vibration Analyzer, or for connecting a cathode-ray oscillograph.

Tubes: One CK533AX, two 1N5-GT tubes and one 1D8-GT tube are required. A complete set of tubes is supplied.

Battery: A single self-contained battery unit, BA48, Burgess 6TA60, which supplies the necessary plate and filament voltages, is included.

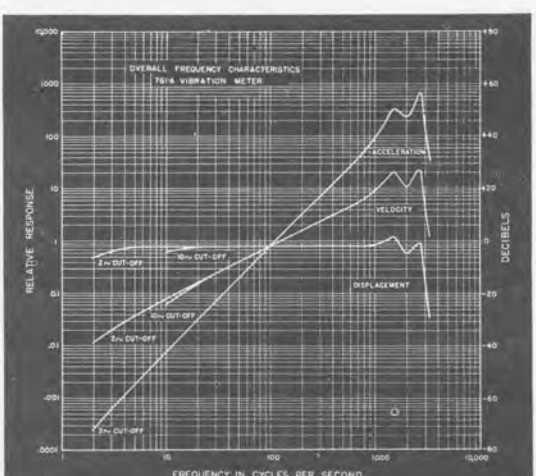
Accessories Supplied: Power cable for calibration check, spare pilot lamp, and plug for output jack.

Case: Shielded carrying case of airplane-luggage construction.

Dimensions: (Height) 12½ inches x (length) 13½ inches x (width) 9½ inches.

Net Weight: 22¾ pounds with battery; 17¼ pounds without battery.

Measurement of automobile-engine vibration with the Type 761-A Vibration Meter.



Over-all frequency characteristics of the Type 761-A Vibration Meter.

Type		*Code Word*	*Price*
761-A	**Vibration Meter**	VIRUS	**$490.00**
761-P1	**Replacement Pickup**	NOSEY	**40.00**
Replacement Battery for above		VIRUSADBAT	**6.25**

TYPE 1551-A SOUND-LEVEL METER

USES: The Type 1551-A Sound-Level Meter is a compact, accurate instrument designed for the general measurement of sound fields. It is ideally suited to the sound-measuring problems of commerce and industry. Manufacturers of machines and appliances use it for measuring product noise both in the development laboratory and in production. For such plants, it provides a means of establishing noise standards, of accepting or rejecting products on the basis of noise tests, and of analyzing and correcting trouble in the rejected units.

Acoustical engineers also use the sound-level meter for determining noise levels from engines, machinery, and other equipment, and for investigating the acoustical properties of buildings, structures, and materials.

Industrial hygienists and psychologists use it in surveys of the psychological and physiological effects of noise, for the establishment of acceptable noise levels, and the determination of satisfactory noise environments in factories and offices.

Accessory equipment, such as frequency analyzers, graphic-level recorders, and magnetic-tape recorders can be operated from the output of the Sound-Level Meter.

It is also suitable for use as a portable amplifier for laboratory standard microphones, and, with a high-fidelity microphone, for measurements on high-fidelity sound systems.

Although the low-cost crystal microphone supplied with the Type 1551-A Sound-Level Meter is satisfactory for the majority of applications, special microphones can be used to full advantage. Among these are the Type 1551-P1 Condenser Microphone System for high-fidelity work, the Western Electric 640-AA where a reproducible standard is desired, and the Type 759-P25 Dynamic Microphone Assembly for use with a long cable or where extreme temperature variations are met.

DESCRIPTION: The Type 1551-A Sound-Level Meter is an accurate, portable, low-priced meter for reading, in terms of a standard reference level, the sound level at its microphone.

It consists of a non-directional microphone, an amplifier, a calibrated attenuator, and an indicating meter.

The complete instrument, including batteries, is mounted in an aluminum case with an easily removed cover over the panel. The microphone is mounted on a bracket and folds down into a panel recess when not in use. In this storage position of the microphone, batteries are automatically turned off. An a-c power supply unit is available.

FEATURES: ➔ Small, compact, and easily portable — weighs only 11 pounds with batteries.
➔ Simple to operate.
➔ Meets all standards of the American Standards Association, the American Institute of Electrical Engineers, and the Acoustical Society of America.
➔ Separate output systems for panel meter and output terminals. When a sound analyzer is used, meter can be used for monitoring.
➔ Two-speed meter movement permits measurement of either steady or fluctuating sounds.
➔ Wide range — from 24 to 140 db.
➔ Sub-miniature tubes in negative feedback amplifier circuits provide excellent stability.
➔ Batteries are readily available.
➔ Amplifiers and panel meter have wide frequency response, 20 cycles to 20 kilocycles.
➔ Low internal noise level.
➔ Internal calibration system for standardizing amplifier gain.

SPECIFICATIONS

Sound-Level Range: From 24 db to 140 db above the standard sound pressure reference level of 0.0002 microbar (a pressure of 0.0002 dyne per square centimeter) at 1000 cycles.

Frequency Characteristics: Any one of 4 response characteristics can be selected by means of a panel switch. The first and second of these are, respectively, the 40 and 70 db equal-loudness contours in accordance with the current standard specified by the American Standards Association. The third frequency response characteristic gives a substantially equal response to all frequencies within the range of the instrument and its microphone. This characteristic is used when measuring extremely high sound levels, when measuring sound pressures, or when using the instrument with the TYPE 760-B Sound Analyzer, the TYPE 736-A Wave Analyzer, or the TYPE 1550-A Octave-Band Noise Analyzer. The fourth frequency response characteristic provides an amplifier which has essentially flat response from 20 cycles to 20 kilocycles, so that full use can be made of extremely wide range microphones such as the W.E. 640-AA or the TYPE 1551-P1 Condenser Microphone System.

Microphone: The microphone is of the Rochelle-salt, crystal-diaphragm type with an essentially non-directional response characteristic. Condenser and dynamic microphones are available as accessories.

Sound-Level Indication: The sound level is indicated by the sum of the readings of the meter and an attenuator. The meter has a range of 16 db, and the attenuator has a range of 100 db in 10 db steps.

Output Terminals: A jack is provided, which supplies an output of 1 volt across 20,000 ohms when the panel meter reads full scale. This output is suitable for use with the TYPE 760-B Sound Analyzer, the TYPE 736-A Wave Analyzer, the TYPE 1550-A Octave-Band Noise Analyzer, a graphic level recorder, or a magnetic tape recorder.

A SLOW-FAST switch makes available two meter speeds. With the control switch in the FAST position the ballistic characteristics of the meter simulate those of the human ear and agree with the current standards of the American Standards Association. In the SLOW position, the meter is heavily damped for observing the average level of rapidly fluctuating sounds.

Calibration: A means is provided for standardizing the sensitivity of the instrument in terms of any a-c power line of approximately 115 volts.

The absolute level of all microphones is checked at several frequencies against a standard microphone, whose calibration is periodically checked by the National Bureau of Standards.

TYPE 1552-A Sound-Level Calibrator (page 15) is available for making periodic checks on the over-all calibration, including microphone.

Accuracy: The frequency response curves A, B, and C of the TYPE 1551-A Sound-Level Meter fall within the tolerances specified by the current ASA standards. When the amplifier sensitivity is standardized, the absolute accuracy of sound-level measurements is within ±1 decibel for average machinery noises in accordance with the ASA standards.

Temperature and Humidity Effects: Readings are independent (within 1 db) of temperature and humidity over the ranges of room conditions normally encountered.

Batteries: Two 1½-volt size-D flashlight cells (Eveready 950 or equivalent); one Eveready 467 B battery or equivalent. Batteries are supplied. The TYPE 1262-A A-C Power Supply is available if a-c operation is desired. (See price table below.)

Tubes: Four CK-512-AX and three CK-533-AX are required. A complete set is supplied with the instrument.

Accessories Supplied: Power Cord (for calibration check), telephone plug.

Other Accessories Available: See pages 12 to 15.

Cabinet: Shielded aluminum and plastic cabinet that also serves as a carrying case.

Dimensions: The over-all dimensions are approximately (height) 6⅝ x (length) 10¹³⁄₁₆ x (width) 8⅞ inches.

Net Weight: 11 pounds, with batteries.

TYPE 1262-A POWER SUPPLY

The sound-level meter is supplied with batteries. For a-c operation the TYPE 1262-A Power Supply attaches to the sound-level meter cabinet, as shown above. Input is 105 to 125 volts, 50 to 60 cycles, 2 watts.

Type		*Code Word*	*Price*
1551-A	**Sound-Level Meter**	MIMIC	**$360.00**
	Set of Replacement Batteries	MIMICADBAT	**3.25**
1262-A	**Power Supply**	MANLY	**75.00**

(Licensed under patents of the American Telephone and Telegraph Company)

VIBRATION PICKUP AND CONTROL BOX

The vibration pickup and control box plug into the sound-level meter in place of the microphone, as shown in the photograph above.

The TYPE 759-P35 Pickup and TYPE 759-P36 Control Box have been designed for use with General Radio Sound-Level Meters.

The TYPE 759-P35 Vibration Pickup is an inertia-operated crystal device which generates a voltage proportional to the acceleration of the vibrating body. By means of integrating networks in the control box, voltages proportional to velocity and displacement can also be delivered to the sound-level meter. The desired response is selected by means of a three-point switch on the control box.

The low-frequency response of the sound-level meter is sufficiently good to permit vibration measurements at frequencies down to 20 cycles. Such measurements include the fundamental and harmonic frequency vibrations of machines rotating at 1200 rpm or higher, as well as many structural resonances.

SPECIFICATIONS

Calibration: The db readings of the sound-level meter can be converted into absolute values of displacement, velocity, or acceleration by means of calibration data.

Range: The range of measurement of the pickup and control box when used with the TYPE 1551-A or the TYPE 759-B Sound-Level Meter is approximately as follows:

R-m-s Displacement — 30 micro-inches (minimum).

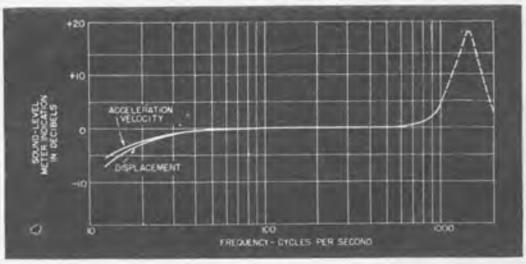
R-m-s Velocity — 1000 micro-inches per second (minimum). The upper limit of velocity and displacement measurements is dependent on the frequency and is determined by the maximum acceleration permissible before non-linearity occurs (10 g).

R-m-s Acceleration — 0.3 to 3900 in./sec/sec (10 g).

Frequency Characteristic: See plot. For frequencies below 20 cycles the TYPE 761-A Vibration Meter should be used.

Mounting: Both control box and pickup are housed in metal containers, finished in black lacquer.

Over-all frequency response characteristic of the vibration pickup, control box, and sound-level meter for constant applied acceleration, velocity and displacement, respectively.



Net Weight: TYPE 759-P35 Vibration Pickup, 8 ounces (pickup only); pickup plus 7-foot cable and tips, 1 pound; TYPE 759-P36 Control Box, 1 pound, 13 ounces.

Type		*Code Word*	*Price*
759-P35	**Vibration Pickup**	NOSEY	**$40.00**
759-P36	**Control Box .....**	NANNY	**50.00**

TYPE 762-B VIBRATION ANALYZER

USES: The TYPE 762-B Vibration Analyzer makes possible the analysis of vibration phenomena having fundamental frequencies as low as 2.5 cycles per second. It is intended primarily for use with the TYPE 761-A Vibration Meter but can also be used for general harmonic analysis of very-low-frequency voltages in the laboratory.

Its range includes practically all frequencies normally encountered in vibration studies, from the fundamental vibrations of ships and other large structures to the unbalance vibrations of high-speed centrifuges.

DESCRIPTION: The analyzer is similar in all essential characteristics of performance, construction, operation, and appearance to the TYPE 760-B Sound Analyzer (page 17) except that the frequency has been lowered by a factor of 10, the output meter has a single logarithmic range, and provision has been made for operation with broad selectivity if desired. The latter arrangement is particularly useful in identifying components in the two lowest frequency ranges (2.5 to 25 cycles per second) and in making analyses involving components that vary slightly about a mean frequency.

SPECIFICATIONS

Frequency Range: 2.5 to 750 cycles, covered in five ranges as follows: 2.5 to 7.5, 7.5 to 25, 25 to 75, 75 to 250, 250 to 750.
Band Width: For the sharp selectivity position, the relative attenuation is approximately 30% (3 db) at a frequency differing by 1% from that to which the analyzer is tuned. For the broad selectivity position, the attenuation is at least 30% for a frequency difference of 5%. At one octave from the peak, the relative attenuations are at least 98% (35 db) and 90% (20 db), respectively.
Frequency Calibration: Sharp selectivity network, $\pm 1\frac{1}{2}\%$ or $\pm 1\frac{1}{2}$ cycles, whichever is the larger, over the three highest ranges (25 to 750 cycles); on the two lower ranges (2.5 to 25 cycles), the accuracy is $\pm 5\%$ or ± 0.2 cycle, whichever is the larger. The frequency as determined with the broad selectivity network deviates on the average by less than $\pm 2\%$ from that determined with the sharp selectivity network.
Frequency Response: The response of the sharp selectivity network is flat within ± 2 db over the entire range. At points where two ranges overlap, the sensitivity is the same on either range within ± 1 db. The sensitivity of the broad selectivity network is the same as that of the sharp selectivity network within ± 2 db.
Net Weight: $34\frac{1}{4}$ pounds, with batteries; $27\frac{1}{2}$ pounds, without batteries.

For other specifications see TYPE 760-B

Type		*Code Word*	*Price*
762-B	**Vibration Analyzer................**	AWARD	**$565.00**

U. S. Patent No. 2,173,426.

TYPE 1550-A OCTAVE-BAND NOISE ANALYZER

USES: The Octave-Band Noise Analyzer makes possible the simple and rapid analysis of noises having complex spectra. Operating from the output of a sound-level meter (page 9), it is more convenient than the Sound Analyzer for those applications where a knowledge of the individual frequency components is not required, and, in addition, is particularly suited for noise measurements on aircraft, vehicles, and machinery, for the analysis of office noise, where speech interference level is the significant factor and for determination of the possible damaging effects of noise on hearing. Another important application is in determining the acoustical characteristics of rooms. It is particularly valuable in production testing and for noise-level acceptance tests.

DESCRIPTION: The analyzer consists of a set of band-pass filters with selection by means of a rotary switch, followed by an attenuator and an amplifier, which drives both an indicating meter and a monitoring output.

The filter is isolated by a resistance pad, which makes the filter characteristics independent of the source, provided the source impedance either is small compared to the 20,000-ohm analyzer impedance or is constant over the audio-frequency range.

FEATURES: ➔ Small, compact, lightweight.

➔ Excellent attenuation characteristics.

➔ Monitoring output is provided.

➔ Meets A.S.A. standards.

➔ Operates from output of the TYPE 1551-A or the TYPE 759-B Sound-Level Meter as well as other sound-level meters with outputs adequately free from noise and distortion.

➔ Can be used directly with microphone for high sound levels.

➔ Amplifier input jack permits amplifier to be used alone.

➔ A-C power supply can be substituted for batteries for laboratory use.

SPECIFICATIONS

Range: 20 cycles to 10,000 cycles in 8 bands,

20 c to 75 c (low pass)	600 c to 1200 c
75 c to 150 c	1200 c to 2400 c
150 c to 300 c	2400 c to 4800 c
300 c to 600 c	4800 c to 10,000 (high pass)

In addition, a band with a flat characteristic from 20 c to 10 kc is available at two switch positions for convenience in calibration against the sound-level meter.

Input Level: Between 1 and 10 volts for normal range. Levels below one volt reduce the range of reading; those higher than 10 volts overload the filters.

Input Impedance: 20,000 ohms. Input is isolated by a resistance pad, so that performance is independent of source if source impedance is constant over audio range or is small compared to 20,000 ohms.

SOUND AND VIBRATION

Source: Sound-level meter supplying analyzer input must have low hum, low internal noise, and low distortion. The TYPE 1551-A or the TYPE 759-B Sound-Level Meter is recommended.

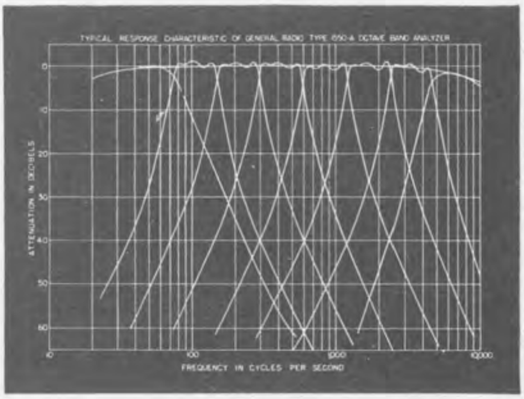
Direct Use with Microphone: The TYPE 1551-P1 Condenser Microphone System or the TYPE 759-P25 Dynamic Microphone Assembly can be used if the band levels exceed 70 db (re 0.0002 μbar). A TYPE 1550-P1 Microphone Adaptor Plug is required with the TYPE 759-P25 Dynamic Microphone Assembly.

Level Indication: Meter calibrated in decibels from -6 to $+10$ db; attenuator covers 50 db in 10 db steps. Level is sum of meter and attenuator readings.

Attenuation: Except for the lowest and highest bands, at least 30-db attenuation is obtained at one-half the lower nominal cut-off frequency and twice the upper nominal cut-off frequency; at least 50-db attenuation is obtained at one-fourth the lower nominal cut-off frequency and at four times the upper nominal cut-off frequency. The 75-cycle low-pass filter has at least 30-db attenuation at 200 c and 50 db at 400 cycles. The 4800-cycle high-pass filter has at least 30-db attenuation at 2400 cycles and 50 db at 1200 cycles.

Tubes: Three 1U4 and one 1T4, all furnished.

Power Supply: Battery, Burgess 6TA60. Battery is included in price. For a-c operation, TYPE 1261-A Power



Supply (page 121) fits battery compartment.

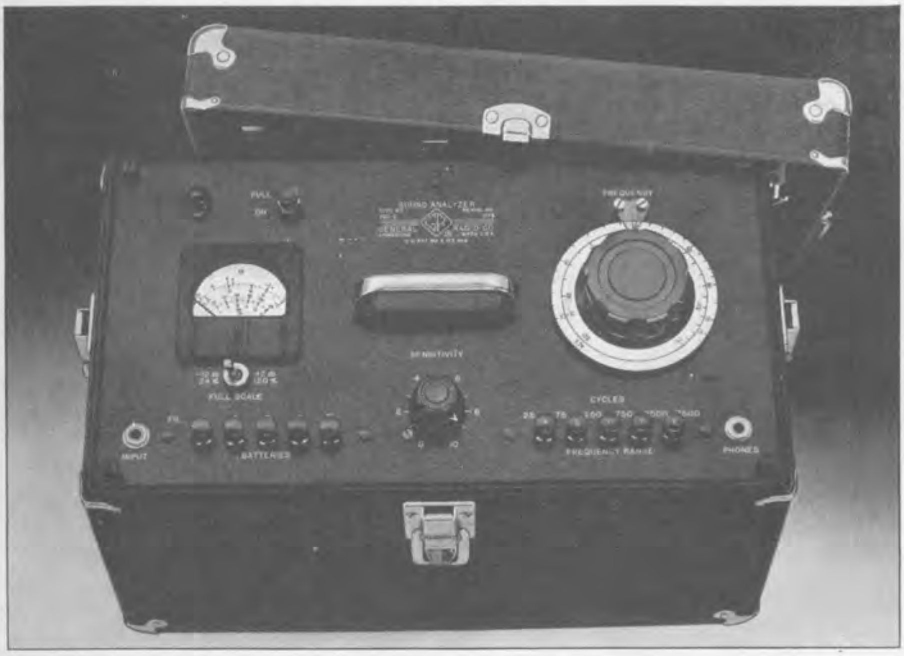
Accessories Supplied: Shielded cable and plug assembly for connecting analyzer to sound-level meter.

Dimensions: (Width) $11\frac{5}{8}$ x (height) $12\frac{9}{16}$ x (depth) 9 inches, over-all.

Net Weight: 27 pounds including battery.

Type		*Code Word*	*Price*
1550-A	**Octave-Band Noise Analyzer**	ABEAM	**$535.00**
	Replacement Battery for above	ABEAMADBAT	**6.25**
1550-P1	**Microphone Adaptor Plug**	MATOR	**4.00**
1261-A	**Power Supply**	NUTTY	**128.00**

TYPE 760-B SOUND ANALYZER



USES: This instrument has been designed particularly for analyzing the noises produced by electrical and mechanical equipment, such as airplane and automobile engines, industrial machinery, and household appliances. It operates from the output of the Sound-Level

Meter and measures the amplitude of each individual frequency component, or pitch, in the noise. This information is valuable in tracing and locating the sources of noise.

In the electrical laboratory, the Sound Analyzer can be used as a harmonic analyzer and as a selective bridge balance indicator.

DESCRIPTION: The circuit is that of a three-stage degenerative selective amplifier having a bandwidth that is a constant percentage of the operating frequency, followed by a voltmeter. The frequency to which the amplifier is tuned is indicated by a single dial and push-button multiplier. The amplitude of the selected component is indicated directly on the meter scale.

FEATURES: ➤ External magnetic fields do not affect readings.

➤ Constant-percentage bandwidth is an advantage for measurements on machines whose speeds fluctuate.

➤ Dial can be rotated continuously in either direction, so that the analyzer can be adapted for automatic recording.

SPECIFICATIONS

Frequency Range: From 25 to 7500 cycles per second, direct reading. This total range is covered in five complete turns of the tuning knob, the ranges on the various dial rotations being 25 to 75, 75 to 250, 250 to 750, 750 to 2500, and 2500 to 7500 cycles. A push-button switch allows immediate change of the main control to any one of these ranges.

Frequency Calibration Accuracy: ±1.5% of the frequency to which the dial is set or ±1.5 cycles per second, whichever is the larger.

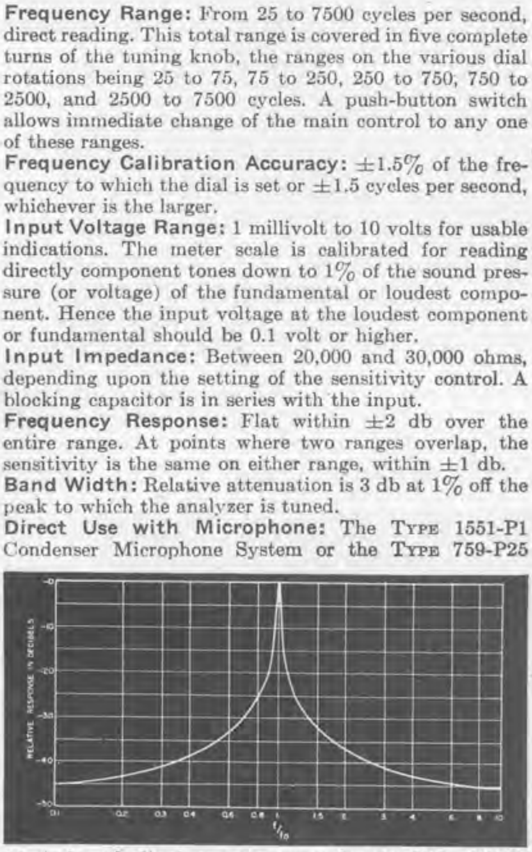
Input Voltage Range: 1 millivolt to 10 volts for usable indications. The meter scale is calibrated for reading directly component tones down to 1% of the sound pressure (or voltage) of the fundamental or loudest component. Hence the input voltage at the loudest component or fundamental should be 0.1 volt or higher.

Input Impedance: Between 20,000 and 30,000 ohms, depending upon the setting of the sensitivity control. A blocking capacitor is in series with the input.

Frequency Response: Flat within ±2 db over the entire range. At points where two ranges overlap, the sensitivity is the same on either range, within ±1 db.

Band Width: Relative attenuation is 3 db at 1% off the peak to which the analyzer is tuned.

Direct Use with Microphone: The Type 1551-P1 Condenser Microphone System or the Type 759-P25 Dynamic Microphone Assembly can be used if the component levels exceed 70 db (re 0.0002 μbar). A Type 1550-P1 Microphone Adaptor Plug is required with the dynamic microphone.



Typical normalized response curve for the Type 760-B.

Temperature and Humidity Effects: Under very severe conditions of temperature and humidity slight shifts in calibration, sensitivity, and bandwidth may occur.

Meter: The indicating meter is calibrated in two ranges. For convenience in use the meter scale is calibrated with the 0 located 2 db below full scale on the meter, so that actual meter scales are +2 to −30 db and −12 to −40 db. Auxiliary percentage ranges of 0 to 120% and 0 to 24% are provided.

Output: A jack is provided on the panel for plugging in a pair of head telephones, in order to listen to the actual component of the sound to which the instrument is tuned. This is also useful when the analyzer is used as a bridge-balance indicator.

Tubes: Three 1L4-type and one 1U4-type are used, together with a neon pilot light (NE-48). All are supplied.

Batteries: The batteries required are four Burgess No. 2FBP 1.5-volt batteries, or the equivalent, and three Burgess No. Z30NX 45-volt batteries, or the equivalent. A battery compartment is provided in the case of the analyzer. Batteries are supplied with instrument.

Accessories Supplied: A shielded cable-and-plug assembly for connecting the analyzer to the sound-level meter.

Case: Shielded carrying case of airplane-luggage construction.

Dimensions: (Length) 18 x (width) 10 x (height) 11½ inches, over-all.

Net Weight: 36½ pounds, with batteries.

Type		*Code Word*	*Price*
760-B	**Sound Analyzer**	ATTAR	**$520.00**
Set of Replacement Batteries for above		ATTARADBAT	**13.10**
1550-P1	**Microphone Adaptor Plug**	MATOR	**4.00**

U. S. Patent No. 2,173,426.

HANDBOOK OF NOISE MEASUREMENT

The Handbook of Noise Measurement is a manual recently published by General Radio Company covering thoroughly the measurement of noise and other airborne sounds. Authors are Dr. A. P. G. Peterson of the General Radio Engineering Staff and Dr. Leo L. Beranek, Director of the Acoustic Laboratory at Massachusetts Institute of Technology.

Copies of this handbook are available from the General Radio Company at a price of $1.00 each, postpaid, in the United States and Canada.