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Improved Transfer Standard for Vibration Pickups

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This paper describes a vibration transfer standard designed to provide comparison calibrations of pickups with minimum degradation. Features of the design are the use of a ceramic housing of a stiff, light, lossy material; provision of a means for evaluating the quality of the motion by the use of three integral accelerometers oriented parallel to the nominal direction of motion; and design of the geometry to minimize differences in motion between the pickup being calibrated and the standard. The useful frequency range is 10–10 000 Hz.

INTRODUCTION

IN most vibration laboratories, calibration of a vibration pickup consists of comparing its output with that of a transfer standard when both are subjected to the same motion. A transfer standard is a standard pickup that can be used to calibrate other pickups conveniently with the accuracy required. Usually the comparison is performed on a calibrator that can be mounted on a shake table with provision for mounting the pickup to be calibrated (the test pickup) on the calibrator. The active portion of the calibrator may be a separate pickup mounted near the test pickup, or it may be an integral part of the fixture. The accuracy of a comparison calibration depends on the characteristics of the standard and of the motion. The various features of an improved experimental calibrator and their influence on the factors that determine the quality of a calibration are described below. The characteristics of the motion applied to the test pickup and the standard depend on a number of factors in addition to the design of the transfer standard. The improved design provides a means for detecting "bad" motion that would cause inaccuracy.

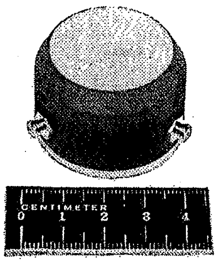

FIG. 1. Assembled standard.

I. DESIGN OF IMPROVED TRANSFER STANDARD

The improved calibrator is pictured in Fig. 1 and shown schematically in Fig. 2. Its principal parameters are given in Table I.

Experience in calibrating vibration pickups by many different techniques at the National Bureau of Standards indicates that defects in the motion cause most of the inaccuracies in a calibration. Among the more serious of such defects are differences in the motion applied to the two pickups, as well as nonaxial and nonsinusoidal motion, all of which are likely to have different effects on the standard and test pickups. The new

TABLE I. Characteristics of improved transfer standard.

Mass	0.110 kg
Height	2.54 cm
Diameter of mounting surface for pickup	3.17 cm
Diameter of calibrator mounting surface	3.81 cm
Typical resonant frequency (mounted)	65 kHz
Typical calibration factor	25 mV (peak)/g (peak)
Material of housing	Sintered aluminum oxide (AD99)
Piezoelectric element	PZT-5
Inertial mass	Carboloy 999
Material of coating for electrical shielding (mounting surfaces not coated)	Moly-manganese
Thickness of Al_2O_3 between test pickup and standard	1.14 cm

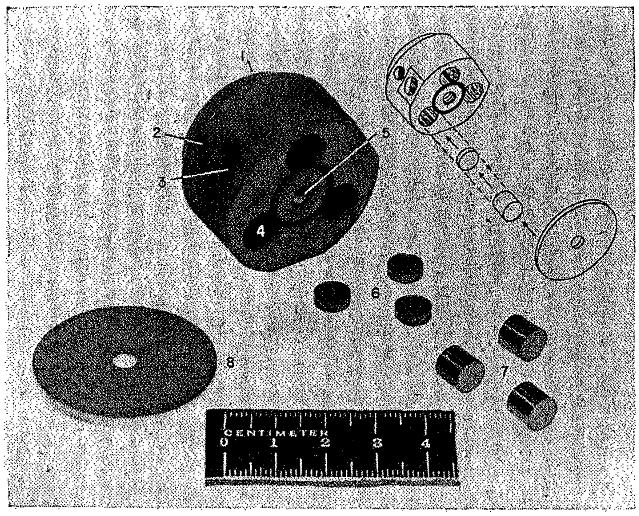

FIG. 2. Parts of standard. 1. Ceramic housing with moly-manganese coating. 2. Hole for spanner wrench. 3. Mounting hole for pickup lead. 4. Recess for pickup elements. 5. Center hole with 10–32 thread. 6. Piezoelectric elements for pickups. 7. Inertial masses for pickups. 8. Ceramic cover plate and bottom mounting surface.

transfer standard is designed to minimize the harmful consequences of such defects in the motion.

The size, shape, and mass of a calibrator directly affect the motion applied to the two pickups. The modes of vibration of the shaker affect the motion of the calibrator and vice versa, while the combination of the two has still another set of resonances. Extremely long, thin shapes tend to promote flexural modes of the shaker–calibrator system and magnify the nonaxial motion at the location of the test pickup. A wide, thin disk is an undesirable shape because it has little resistance to nonuniform surface motion of the shake table at higher modes of vibration and, at some frequencies, may even *promote* such nonuniform motion. The calibrator should be light, compact, and stiff so that its resonances and its effect on the resonances of the shaker will be out of the frequency range of interest as much as possible. The shape shown in Figs. 1 and 2 represents the best compromise we have found between these requirements and the needs for mounting space.

The choice of sintered aluminum oxide for the housing is one of the most important features of the design. It has been found to have considerable advantages over more usual materials for shake tables and pickups.[1] Its properties are compared with those of other materials used for vibration fixtures in Table II.

Because of the low density, the calibrator loads this shaker less than it does one of a similar size and shape made of more usual materials. Because of the combination of low density and high Young's modulus together with considerable damping for such a stiff material, the frequency at which wave motion becomes signficant is well above the frequency range of interest. Hence, inaccuracies due to different motion of the test pickup and the standard are minimized, whether the differences are caused by different deformations, by each pickup, of the mounting surfaces or by a mode of vibration of the mounting surface that provides more motion at one location than at another.

In this calibrator, the standard consists of the combination of three small pickups mounted in wells on the underside of the surface on which the test pickup is mounted. The use of the same pickups to determine when the motion is free of defects that might cause inaccuracy is described in a later section. Each of the small pickups built into the calibrator consists of an active element of lead zirconate–titanate piezoelectric ceramic and an inertial mass of tungsten carbide. The parts of the pickup are cemented together with a silver-filled epoxy, which is also used to cement the pickup to the calibrator. The construction is adapted from a technique described previously,[2,3] which is one of a number of techniques developed at NBS to provide vibration pickups for special applications for which suitable commercial instruments were not available.[4–7] With this background to draw on, we are reasonably sure that the type of construction used will produce as good stability of the calibration factor over long periods of time as the type of piezoelectric material allows.

Since the sintered aluminum oxide is an electrical insulator (see Table II), the pickups are isolated from

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[1] E. Jones, J. Acoust. Soc. Am. 36, 1215–1216 (1964).

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[3] E. Jones, S. Edelman, and E. R. Smith, 23rd Shock and Vibration Bulletin (1956).

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[6] S. Edelman, E. Jones, and E. R. Smith, J. Acoust. Soc. Am. 27, 728–734 (1955).

[7] J. E. McKinney, S. Edelman, and R. S. Marvin, J. Appl. Phys. 27, 425–430 (1956).

TABLE II. Properties of materials used for vibration fixtures (typical values).[a]

Material	Modulus of elasticity (psi)	Specific gravity	Thermal coefficient of expansion (in./in.·°C)	Electrical resistivity (μΩ·cm)
Alumina (Al_2O_3)	54×10^6	3.7	7.8×10^{-6}	10^{21}
Steel	30×10^6	7–8	18×10^{-6}	15–20
Aluminum	10×10^6	2.5–2.8	24×10^{-6}	6
Tungsten carbide	105×10^6	15.25	4.0×10^{-6}	17
Tungsten	59×10^6	19.4	4.0×10^{-6}	6

[a] Adapted from T. Dimoff, J. Acoust. Soc. Am. 40, 671–677 (1966).

TABLE III. Results of calibration of NBS transfer standard No. 109.

Frequency (Hz)	Calibration factor (mV/g)	Gain of cathode follower
10	24.7	0.9667
15	24.7	0.9707
30	24.8	···
50	24.8	0.9744
100	24.8	0.9746
200	24.8	0.9748
500	24.7	0.9747
900	24.8	···
1700	24.6	0.9747
2000	24.7	···
2500	24.7	···
3000	24.8	···
3500	24.6	···
4000	24.9	···
4500	25.1	···
5000	25.0	0.9747
5500	25.0	···
6000	25.0	···
6500	25.2	···
7000	25.2	···
7500	25.2	···
8000	25.3	···
8500	25.3	···
9000	25.3	···
9500	25.3	···
10 000	25.4	0.9746

each other and from ground except where connections are deliberately introduced. Electrical shielding is provided by a coating of moly-manganese electrolytically deposited on the surfaces indicated in Fig. 2. The top and bottom mounting surfaces are left uncoated so that they are electrically insulating.

The high value for the mounted resonant frequency of the pickups helps minimize the inaccuracy caused by harmonic distortion in the motion. If a calibration is performed to 10 kHz, the response of the standard to distortion even as high as the third harmonic will not be too much different from its response to the fundamental. However, inaccuracy in the calibration may occur if the response of the test pickup to the third harmonic is much different from its response to the fundamental; but such inaccuracy will depend on the characteristics of the test pickup rather than on the characteristics of the standard.

II. BEHAVIOR AS STANDARD PICKUP

The frequency response of a typical transfer standard is given in Table III. Transfer Standard No. 109 was calibrated on the NBS vibration standards by the methods used in routine calibrations. The output terminals of the three sensing elements were connected in parallel into a cathode follower. The transfer standard was attached to the shake table with a stud that permitted the base of the standard to be in direct contact with the mounting surface. The contacting surfaces were coated with medium petroleum lubricating oil. A solid, cylindrical 28-g stainless-steel mass, 1.59 cm in diam, was mounted on top of the standard to simulate the effect of a pickup. The standard and the weight were tightened with a torque of 18 lb-in. The results are shown in Table III. The calibration factor is the ratio of the open circuit output of the cathode follower in millivolts (peak) to the acceleration in *g* (peak). The effect of other masses is being studied.

III. USE TO EVALUATE QUALITY OF MOTION

As noted above, most errors in calibration are caused by bad motion. Nonsinusoidal motion can be detected by analyzing the pickup output with a distortion analyzer. There is no similarly simple way to detect other kinds of bad motion. For example, at the frequencies of flexural resonances of the shake table and at the resonant frequencies of higher-order modes of vibration of fixtures, large-amplitude nonaxial motion can occur. Such motion may generate unusually clean sinusoidal signals from the pickups. The sensitivity of the pickup for such excitation usually is much different from its sensitivity when the motion is axial.

The three pickups in the transfer standard provide a sensitive means for detecting nonaxial motion of the pickup being calibrated. The outputs of each of the three internal pickups and the output of the pickup being calibrated are used in pairs to form Lissajous figures. The three Lissajous figures formed by the internal pickups and one or more formed by combining the output of one of the internal pickups with the pickup being calibrated are exhibited on an oscilloscope. At a low frequency where the motion is good, the gains of the various amplifiers are adjusted so that each figure is a straight line at 45° to the vertical. As the frequency of vibration is changed, bad motion shows as changes in one or more of the lines. Rotation of the surface of the shake table about any axis through the table, or breakup of the surface motion into higher modes, causes one or more of the figures generated by the internal pickups to become an ellipse. Rotation about an axis outside the table is shown by rotation of one or more of the traces away from the 45° position. Motion of the central portion of the table out of phase with the motion of the periphery shows as opening of the figure that uses the signal from the pickup being calibrated. Various combinations of the different modes may occur.

Purely transverse components of the motion of the shake table are not detected by this calibrator. However, we assume that the transverse components of the motion of a shake table are always accompanied by other undesirable components which are detected by this calibrator. This conclusion is supported by the results of many experiments under various conditions and with many different shakers.

The interpretation of signals from the internal pickups to determine when the motion of the shaker is suitable for accurate calibration requires much experience and study. The motion is obviously unsuitable if the oscilloscope traces show ellipses or lines far from 45°. However, with experience, one can detect much less obvious bad motion by small changes in the Lissajous figures as the frequency is changed. A correlation has been noted between bad motion detected by the calibrator and erratic results of the calibration. Data are being gathered now to demonstrate the connection quantitatively. Enough work has been performed to make it possible to say with assurance that the results of a calibration in the useful frequency and amplitude ranges of a pickup will be reproducible when the calibrator indicates that the motion is good. When the results given in Table III are used to calibrate a pickup by comparison with this transfer standard, we estimate that the over-all uncertainty is less than 2% when used in a temperature-controlled laboratory.

IV. CONCLUSION

For most vibration laboratories, we believe that a device of the type described in this paper will be useful principally as a transfer standard, that is, a standard pickup that can be used to calibrate other pickups conveniently with the accuracy needed. For the few laboratories concerned with calibrations of the best attainable accuracy, the principal usefulness of the device will be to monitor the motion during calibration.

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