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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

THE MEASUREMENT AND ANALYSIS OF LINEAR AND TORSIONAL VIBRATIONS WITH ELECTRONIC INSTRUMENTS

● THE CURRENT DIFFICULTY in obtaining instruments and equipment, irrespective of priority rating, has focused attention on the problem of extending the usefulness and application of instruments already on hand. One of the most fruitful possibilities in this direction is that of utilizing sound-measuring and analyzing equipment for the study of vibrational phenomena.

The study of the theoretical as well as the practical aspects of vibrations in mechanical systems has been greatly stimulated by the current emphasis on the mechanical side of warfare. The development of fast fighting planes, long-range bombers, high-speed torpedo boats, and armored vehicles depends, in no small measure, on the ability to measure and to control vibrations in the machinery and struc-

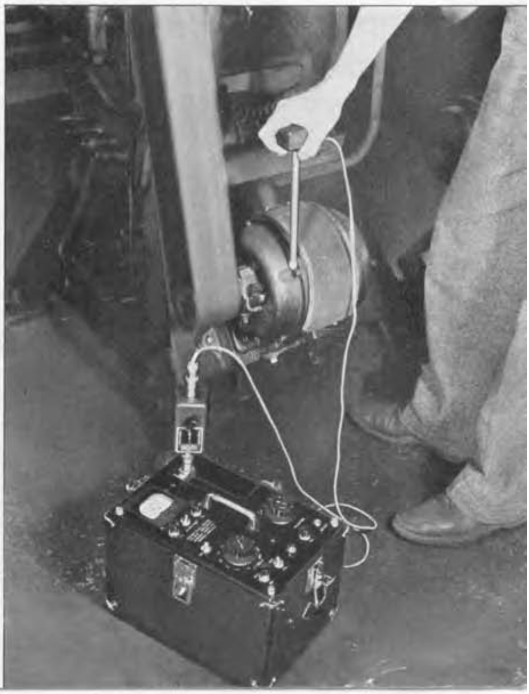


Figure 1. Measuring vibration in a punch-press motor with the vibration pickup and sound-level meter.

ture. The present article will show that, if suitable pickup mechanisms are available, the TYPE 759-B Sound-Level Meter and the TYPE 760-A Sound Analyzer (or the TYPE 736-A Wave Analyzer) can be used for satisfactory measurement and analysis of linear and torsional vibrations. One or more of these instruments will be found in most industrial research laboratories.

LINEAR VIBRATIONS

The TYPE 759-B Sound-Level Meter can be readily adapted for vibration measurements simply by replacing the microphone with a suitable vibration pickup. Since this instrument has a high input impedance, for use with a crystal microphone, a crystal pickup can be substituted directly.

The reading of the sound-level meter will be a measure of the acceleration[1] of the vibrating member to which the pickup is applied, because the crystal pickup, as commonly manufactured, is inertia-operated. More frequently, however, an indication of the *amplitude* of the vibration, independent of frequency, is desired, and occasionally a measure of vibration *velocity*. Fortunately it is a simple matter to convert the output voltage of the pickup to a voltage that is proportional to velocity or displacement. The voltage across the condenser in a series resistance-capacitance circuit is proportional to the integral of the impressed voltage at all frequencies for which the reactance of the condenser is small compared to the series resistance. Acceleration integrated once gives velocity, and the velocity integrated once gives displacement, so that a simple combination of resistors and condensers, together with a selector switch, can be used to provide any one of the three types of response.

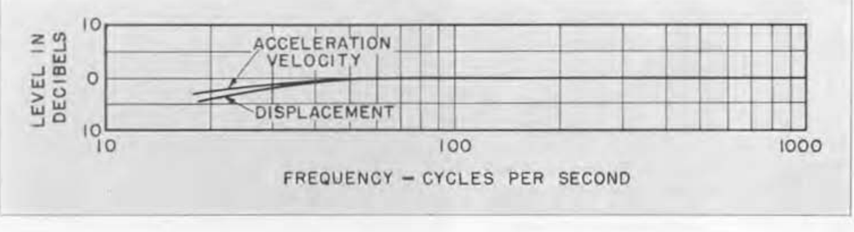
The TYPE 759-P35 Vibration Pickup and the TYPE 759-P36 Control Box, designed particularly for use with the TYPE 759-B Sound-Level Meter, have been available for some time.[2] The design of the control box is such that flat response is maintained to a frequency very close to the resonant frequency of the crystal pickup. Calibration figures are supplied, so that the decibel readings of the Sound-Level Meter can be converted to absolute values of vibration displacement, velocity, or acceleration. Figure 2 shows the over-all frequency response of a pickup, control box, sound-level meter combination. The low-frequency response is limited by the response of the amplifier in the sound-level meter, which, in its normal application, is not required to amplify frequencies below 20 or 30 cycles per second.[3]

[1]This is equivalent to saying that, for a constant amplitude, the response is proportional to the square of the frequency.

[2]Literature describing these units will be sent on request.

[3]The TYPE 761-A Vibration Meter, an instrument that is functionally identical to the combination described above, was announced in the June, 1941, *Experimenter*. Being specifically designed for vibration work, however, this instrument is direct reading in vibration displacement, velocity, and acceleration, and can be used at frequencies as low as 2 cycles.

FIGURE 2. Over-all frequency response of the vibration pickup, control box, and sound-level meter.



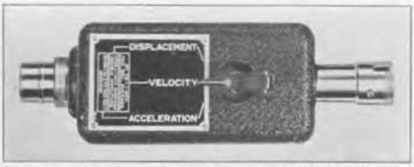


FIGURE 3. View of the TYPE 759-P36 Control Box. Nominal calibration data are given on the nameplate.

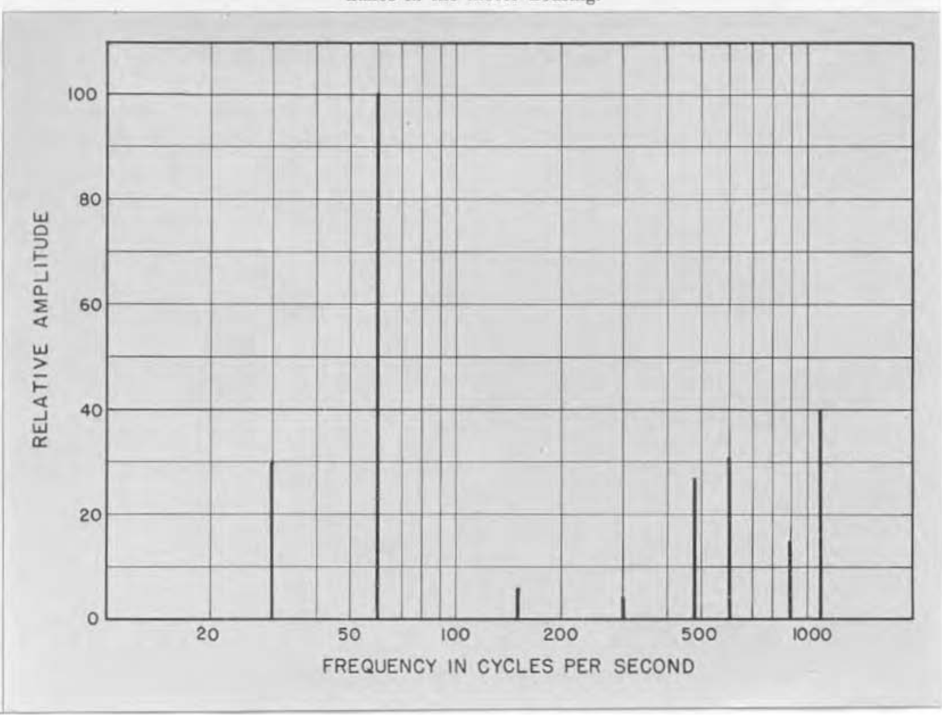
ANALYSIS

In many applications a knowledge of the frequency distribution and the relative amplitudes of the various components of the vibrational disturbance is important. If the TYPE 760-A Sound Analyzer is used at the output of the sound-level meter, the entire vibration spectrum can be scanned in a few minutes, and the frequency and magnitude of the significant components noted. In Figure 4 is shown an analysis, made with the equipment described above, of the vibrations occurring in a large surface grinder.

The TYPE 736-A Wave Analyzer may also be used to evaluate the frequency components of the output voltage of the sound-level meter. The selectivity of this analyzer,[4] however, is so high that unless the vibration is very stable, it may be difficult to obtain satisfactory readings at the higher frequencies. Furthermore, at the lower frequencies, the band width of 4 cycles may be too broad to obtain a satisfactory separation of non-harmonic components that may fall very close together in frequency. In addition, the instrument is somewhat bulky as compared to the TYPE

[4]The band width is approximately 4 cycles, and is independent of frequency. In contrast to this, the TYPE 760 has a constant fractional band width, giving the same effective separation and tuning stability at all frequencies.

FIGURE 4. Frequency analysis of the vibrations occurring at the exhaust horn of a vertical grinding machine. The large component at 60 cycles corresponds to the second harmonic of the rotational speed of the driving motor. The 1100-cycle component is caused by a resonance in the motor housing.



760 and requires preliminary adjustments that are relatively critical compared to the simplicity of operation of the TYPE 760.

TORSIONAL VIBRATION

Of utmost importance in the design and testing of cam shafts, drive shafts, propellers, and other rotating mechanisms that transmit or deliver power is a knowledge of the frequency and amplitude of the torsional vibrations that exist. Only when a means for measuring such vibrations is available can an intelligent program be directed toward their reduction or elimination.

Perhaps the most widely accepted method of analyzing torsional vibrations is to make an oscillogram of the vibration, using a torsional pickup, integrating amplifier, and recording oscillograph.[5] A mechanical harmonic analyzer is then used to obtain the magnitudes of the different components of the complex wave. Although this method is admittedly the most thorough (it yields the phase relations as well as the amplitudes), its use has been somewhat limited by the relatively high cost of the

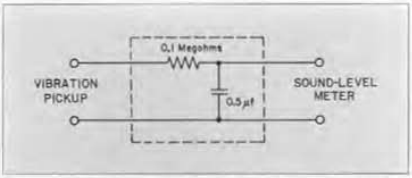


FIGURE 5. A simple integrating network that can be used to convert the output of the No. 89246 torsional pickup to a voltage proportional to angular displacement.

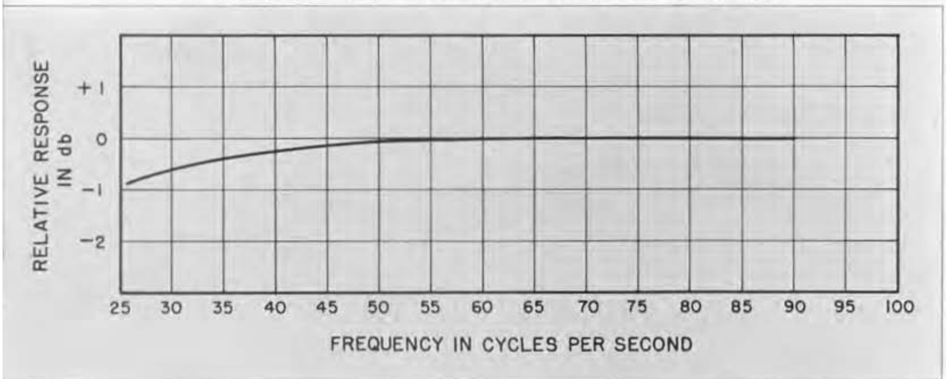
equipment involved and by the fact that considerable time is consumed in developing and analyzing the records. For production or maintenance testing, in particular, the latter objection can become sufficiently serious to rule out the method.

Owing to the speed and convenience with which measurements can be made, the combination of sound-level meter and analyzer offers an attractive possibility for use in conjunction with a torsional pickup. Tests made with a Sperry[6] pickup (No. 89246) indicate that entirely satisfactory performance can be obtained from a lower limit of 25 cycles to an upper limit determined solely by the pickup. This type of pickup, when mounted against a shaft, is insensitive to the steady-state angular

[5] The sound analyzer has been found extremely useful with this equipment, since it is often desirable to know, while the tests are being run, what the frequencies and relative amplitudes are.

[6] Vibration pickups, amplifiers, and recorders formerly manufactured by the Sperry Gyroscope Company are now made and sold by Consolidated Engineering Corp., 1255 East Green Street, Pasadena, California.

FIGURE 6. Over-all response of the torsional pickup, the integrating network of Figure 5, and the TYPE 759-B Sound-Level Meter. Data were not taken above 90 cycles because of the limitations of the mechanical calibrator used, but an essentially flat response should be maintained to about 1000 cycles, the upper frequency limit of the pickup.



motion, but produces a voltage proportional to the angular velocity of any torsional vibration that is superimposed. To convert this voltage to a voltage proportional to amplitude of angular displacement, it is only necessary to integrate once, using a series resistance-capacitance circuit. A satisfactory integrating network can be made with a 0.1-megohm resistor and a 0.5 μf condenser, as shown in Figure 5. The response of the sound-level meter with the network of Figure 5 interposed between pickup and amplifier is shown in Figure 6. A constant calibration amplitude of 2.02 degrees was maintained as the frequency of vibration was varied from 25 cycles to 90 cycles.[7] The minimum measurable amplitude is limited by the sensitivity of the pickup to about 0.1° at a frequency of 60 cycles, while the maximum amplitude that can be measured is essentially limited by the maximum angular displacement that the pickup can safely accommodate. The response of the pickup is linear up to 10° double amplitude.

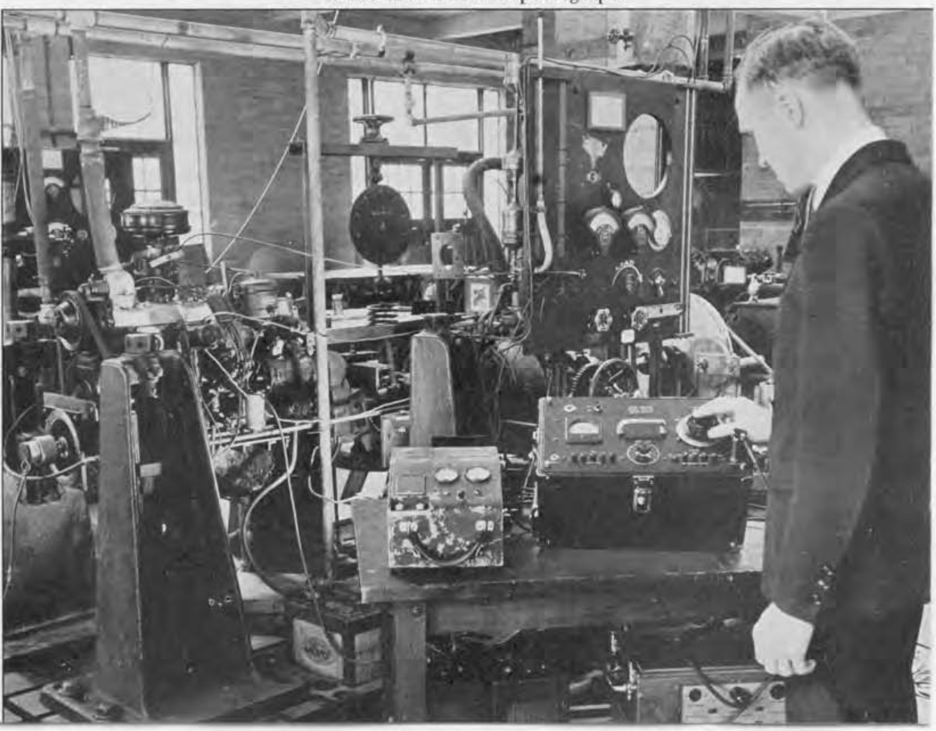
Here again, the use of the Type 736-A Wave Analyzer (directly across the output of the integrating network) is feasible but, as previously explained, is not generally as satisfactory as the scheme outlined above.

While of course it cannot be pretended that the various arrangements discussed above can completely replace equipment specifically designed for vibration measurement and analysis, experience has shown that entirely satisfactory results can be had in the study of vibrations at frequencies above 20 or 25 cycles.

—Ivan G. Easton

[7]This test was made in the laboratories of the Ranger Engineering Corporation, Farmingdale, Long Island, New York.

Figure 7. The Type 760-A Sound Analyzer set up for analyzing torsional vibration. The pickup is shown on the end of the crankshaft at the extreme left. The sound-level meter is not shown in this photograph.

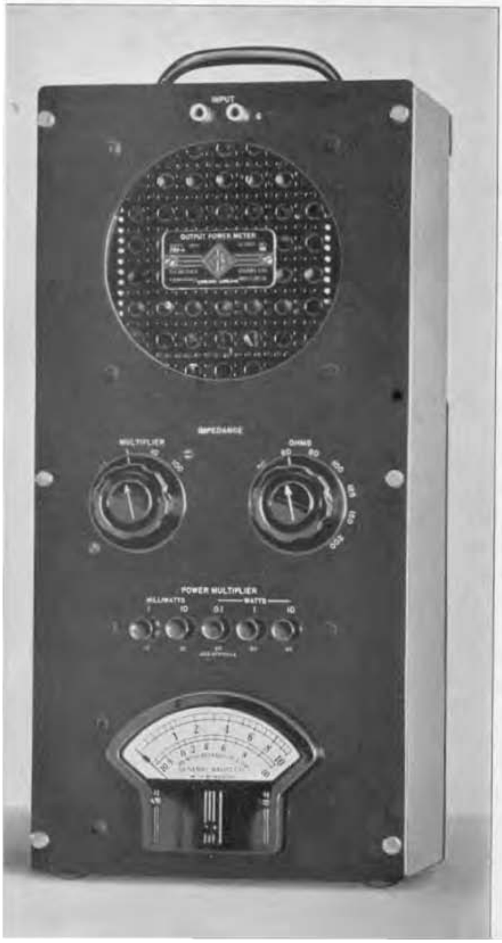


A 100-WATT OUTPUT POWER METER

● THE OUTPUT POWER METER for power-output and internal-impedance measurements on radio receivers, amplifiers, and oscillators was first introduced by General Radio nearly ten years ago.* Over a thousand of these instruments have been sold and, with the development of the art, their general utility around the communications laboratory is constantly increasing.

*"A Power Meter with a Wide Frequency Range," *Experimenter*, May, 1932. "A Direct-Reading Meter for Power and Impedance Measurements," *Experimenter*, November, 1932.

FIGURE 1. Panel view of the TYPE 783-A Output Power Meter.



It has been evident recently that there exists a field for an instrument of the same type but capable of dissipating greater amounts of power, and the new TYPE 783-A Output Power Meter has been designed to meet this need.

Nearly as sensitive at low power levels as the older TYPE 583, this new instrument has a much wider power range extending to a maximum of 100 watts. The power scale on the indicating meter extends from 0 to 10, and is used in conjunction with a set of five push-button-operated decade multipliers. An auxiliary decibel scale is provided on the meter, extending from −10 db to +10 db, referred to a level of 1 milliwatt.

The impedance range is 2.5 ohms to 20,000 ohms, covered by means of two switches, one direct reading in ohms, the other a multiplier.

The accuracies of both power and impedance indications are maintained over a considerably wider frequency range than in the TYPE 583.

A functional schematic diagram of the TYPE 783-A Output Power Meter is given in Figure 2. As can be seen from this diagram, the instrument is equivalent to an adjustable load impedance, across which is connected a voltmeter calibrated directly in watts dissipated in the load. It consists essentially of a voltage divider and an autotransformer for adjusting the impedance level, and a set of resistive pads for adjusting attenuation.

The operation of the output power meter is extremely simple. For measuring the power that a circuit is capable of delivering into a given impedance, the impedance switch and multiplier are set to the desired value, and the power is then indicated by the meter and its multiplier. The internal impedance of the source under test can also be determined since it is equal to the impedance into which maximum power is delivered.

The output power meter is extremely useful in experimental work where a number of power and impedance measurements must be made as the characteristics of the circuit under measurement are varied. It is a valuable aid in the design and testing of amplifiers, oscillators, filters, transformers, and other networks, in making standard tests on radio receivers, and in measuring the power output of vacuum tubes. Its impedance range is wide enough to simulate all types of loudspeakers, and its sensitivity is sufficient to measure directly the output and internal impedance of a magnetic phonograph pickup.

Another use is in the measurement of the loss in a transformer working out of a given source impedance. The maximum output of the source is determined, after which the transformer is interposed between the source and the meter, and the maximum output of the transformer is found. The difference between the two readings on the decibel scale gives the transformer loss directly.

SPECIFICATIONS

Power Range: 0.2 milliwatt to 100 watts in five ranges (10 and 100 milliwatts, 1, 10, and 100 watts, full scale). An auxiliary decibel scale reads from −10 to +50 db referred to a level of 1 milliwatt.

Impedance Range: 2.5 to 20,000 ohms. Forty discrete impedances, distributed approximately logarithmically, are obtained by means of a ten-step OHMS dial and a four-step MULTIPLIER.

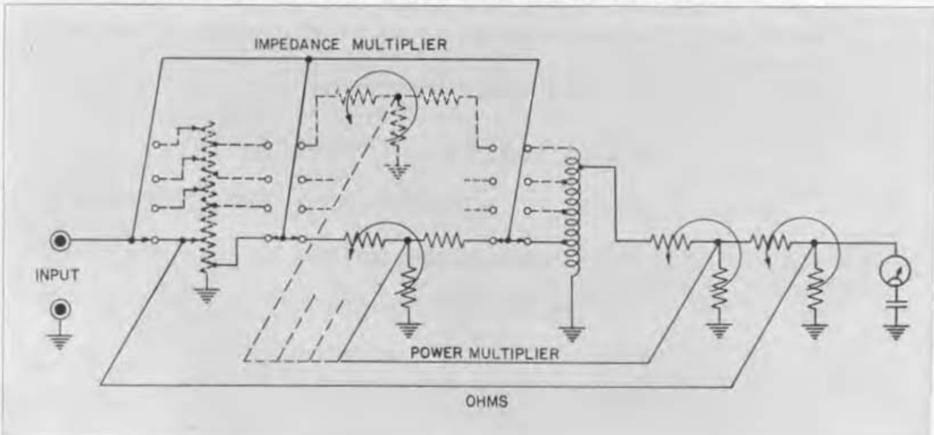
Impedance Accuracy: The input impedance is within ±2% of the indicated value, except at the higher audio frequencies, where the error for the higher impedance settings may exceed this value. At 15,000 cycles the input impedance error is about 5% for impedances from 10,000 to 20,000 ohms.

Power Accuracy: The indicated power is accurate to ±0.25 db at full-scale reading. At the lowest impedance multiplier setting (2.5 to 20 ohms) there may be an additional error of 0.2 db due to switch contact resistance when the power multiplier is set at 10 (10 to 100 watt range).

The over-all frequency characteristic of the power indication is flat within ±0.5 db from 20 cycles to 10,000 cycles; within ±0.75 db to 15,000 cycles.

Waveform Error: The indicating instrument used is a copper-oxide rectifier meter, calibrated in r-m-s values for a sinusoidal applied voltage. When non-sinusoidal voltages are applied an error in indication may occur, since the meter is not a true r-m-s indicating device. The error

FIGURE 2. Schematic circuit diagram of the TYPE 783-A Output Power Meter.



will depend on the magnitude and phase of the harmonics present, but, with waveforms normally encountered in measurement circuits at communications frequencies, will not be serious.

Temperature and Humidity Effects: Humidity conditions have a negligible effect on the accuracy of the instrument.

The instrument is calibrated at 77° Fahrenheit, and if the ambient temperature departs widely from this value, additional errors of indication may be expected. At high temperatures (95° Fahrenheit) this additional error may approach the nominal calibration error, particularly at the higher frequencies.

The heat dissipated by the instrument itself has no effect on the accuracy.

Accessories Supplied: One TYPE 274-M Plug.

Mounting: The instrument is mounted on a bakelite panel in a walnut cabinet.

Dimensions: 8 x 18 x 7 inches, over-all.

Net Weight: 17 pounds.

Type		*Code Word*	*Price*
783-A	Output-Power Meter........	ABBEY	$185.00

This instrument is manufactured and sold under United States Patents Nos. 1,901,343 and 1,901,344.

RUBBER-COVERED CABLES

● **FOR THE PRESENT**, at least, we have sufficient rubber-covered power-supply cables and concentric-shielded cables on hand to supply with new equipment. We cannot yet estimate how long our supply will last, but as long as it does we will continue to furnish them. In the meantime we are searching for adequate substitutes.

Because of the now very limited supply, we are sorry that we will not be able to furnish rubber-covered cables either as spares with new equipment or for replacements. Although we believe that the cables we now supply as standard accessories are the best available, there are adequate substitutes for the power cables. Users are urged to conserve and repair broken concentric conductors, however, because substitutes for these, not employing rubber, are much more difficult to find.

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