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Reprint October 1959

# Microphonics in Vacuum Tubes.

by

*Henry Petersen, M.Sc.*

**SUMMARY**

In the following article some methods for measuring the microphonics in vacuum tubes are described. Furthermore, different ways of exciting the tube under test are discussed. The vibration excitation of the tube is developed in three essentially different manners, by means of a vibrating table, by exposing the tube to sound vibrations, and by tapping the tube mechanically.

Finally, the applications of the different procedures are briefly discussed.

**SOMMAIRE**

L'article suivant décrit quelques méthodes de mesure du microphonisme des tubes à vide. On y étudie également diverses manières d'exciter les tubes soumis au contrôle. L'excitation vibratoire du tube peut être obtenue de trois manières differentes: par l'emploi d'une table vibrante, en exposant le tube aux vibrations sonores, en soumettant le tube à des impulsions mécaniques.

L'article se termine par une brève discussion de la mise en application des divers procédés étudiés.

**ZUSAMMENFASSUNG**

Der folgende Artikel beschreibt einige Verfahren für die Untersuchung der Mikrophonie von Elektronenröhren. Diese können auf verschiedene Weise zu mechanischen Schwingungen erregt werden: ·mit Hilfe eines Schwingtisches, durch Einwirkung von Schwellen sowie durch mechanisches Klopfen.

## Introduction.

Microphonics are by definition the spurious electrical signals which are developed in an electrical unit when subjected to mechanical vibrations. Such signals occur in most of the components used in tele- and radioapparatus, but are normally produced mainly in the vacuum tubes employed. This is due to the fact that the suspension of the electrodes in a vacuum tube is not completely rigid, whereby mechanical vibrations applied to the tube, make the electrodes oscillate. These oscillations cause changes in the small distances between the electrodes, and because the characteristic data of the tube as for instance the anode current and the amplification factor are functions of these distances, the oscillations produce electrical signals.

Due to the many different modes of oscillation which are possible, the output signal from the tube must be expected to be rather complex, containing a number of different resonance frequencies. A frequency analysis of such a signal must consequently include many peaks with different heights and steepnesses. It is, furthermore, to be expected that the height of the different peaks depends on the direction of the vibrating force, because one vibration-direction causes one electrode to oscillate with its maximum amplitude, and another vibration-direction gives another electrode maximum amplitude.

It is seen that several independent variables are involved when measurements of microphonics are carried out. Although all the different measuring conditions are stated before measurements take place, it is not sure that the reproducibility is one hundred percent. This is because the tube-microphonic itself is a phenomenon which varies as a function of the pre-history of the tube. If for instance the tube is shaken vigorously between two measurements, the two measurements obtained are not identical but differ more or less.

In the following some illustrative examples are given on the results obtained from measurements of microphonics. The investigations are in this case not carried out to find out from where the disturbances arise, but only to show and judge some practical measuring methods. The tubes under test are all coupled as triodes with the components and supply voltages corresponding to the ones used as examples on normal working conditions in the data sheets for the actual tubes.

**Exciting by Means of a Vibrating Table.**

One of the first problems which comes up when the measurements are to be carried out by means of a shaker is, how the tube should be suspended. As previously mentioned, the direction of the vibrating force may be expected to influence the measured results. The method which theoretically would give the best results would, consequently, be to let the force act in all directions successively. This would, however, in practice involve severe problems, and make the measurements very tedious.

A practical and reasonable solution is to vibrate the tube with a force which has equal components in three directions at right angles to each other and to let one of the components coincide with the axis of the tube. If the three directions are called x, y, and z, and the total force P, the following equations must be fulfilled:

$$P^2 = P_x^2 + P_y^2 + P_z^2$$
$$P_x = P_y = P_z$$

From this $P_x = \frac{P}{\sqrt{3}} \sim P \cos 55°$.

The axis of the tube must consequently be placed at angle of 55° with the direction of the vibrating force.

The magnitude of the vibrating force must be chosen according to the vibration level to which the tube should be exposed. For tubes used in aircrafts, missiles, ships or the like, the actual vibration levels vary over a very wide range. Normally, however, certain microphonic tolerances are specified in every special case, and the test vibration level must, consequently, be chosen according to this. In these cases an almost pure mechanical excitation is present. The excitation may also be produced by sound waves. If f. inst. it is assumed that the only force acting on the tube under its normal working conditions is a certain sound pressure p dyne/cm², the magnitude of the corresponding force must be K = pA dyne where A is the apparent area in cm² of the tube facing the sound source. If m is the mass of the tube in grammes, and G is the acceleration due to gravity in cm/sec², the acceleration g of the tube in terms of G is

$$g = \frac{pA}{mG}$$

For a normal tube we may use:

$$A = 10 \text{ cm}^2 \text{ and } m = 10 \text{ grammes.}$$

With a sound pressure level of 130 db re $2 \times 10^{-4}$ $\mu$bar, the corresponding acceleration is found:

$$g_{130} = \frac{2 \cdot 10^{-4} \cdot 3.2 \cdot 10^{6} \cdot 10}{10 \cdot 981} G \sim 0.7 \text{ G}$$

Thus it is sufficient to shake the tube with a maximum acceleration of

1.0 G.

For this purpose a very small shaker is sufficient.

The next thing which must be considered is the frequency range in which the measurements must be carried out. For any a.f. equipment this range must be chosen as a part of the range 20 to 20ooo c/s or the entire range. In this case the BFO Type 1014 is excellently suited as vibration exciter control for the shaker.

For a lower frequency range (5 to 4ooo c/s) the Automatic Vibration Exciter Control Type 1016 or the BFO Type 1015 could be used, and for a higher frequency range (200 to 200ooo c/s) the BFO Type 1013 may be employed. All these instruments feature a regulating amplifier section which reduces the frequency characteristic of the shaker to a matter of secondary importance. This is attained by feeding an electrical signal proportional to the instantaneous vibration level to the regulating amplifier. The exciter output is then regulated to provide a constant vibration level for any change that is smaller than 45 db. The frequency characteristic of the shaker system is, consequently, only of interest in so far that the maximum ratio between the highest and the lowest input voltage necessary to give a constant vibration level must be equal to or smaller than 45 db.

As regulating voltage can be used the output signal from one of the Accelerometers Type 4308 or 4309. With a frequency characteristic which is flat from 5 to 20ooo c/s (30ooo c/s for Type 4309) the Accelerometer ensures a perfect regulation in any frequency interval within these limits. To ensure a low limiting frequency, the input impedance of the succeeding amplifier, however, must be high. As can be seen from Fig. 1 which shows a set-up for a frequency sweep test, the Accelerometer Type 4309 is followed by the Preamplifier Type 1606 and the Microphone Amplifier Type 2603. The frequency characteristic of the Microphone Amplifier being flat from 2 to 35ooo c/s, does not decrease the useable frequency range. The measuring arrangement, moreover, functions as follows: The BFO, which is the upper instrument in the A.F. Response and Spectrum Recorder Type 3320 feeds the energizing coil of the shaker. Inside the tubeholder, designed so that the axis of the tube has an angle of 55° with the direction of the vibrating force, an Accelerometer Type 4309 is placed. The output signal from this

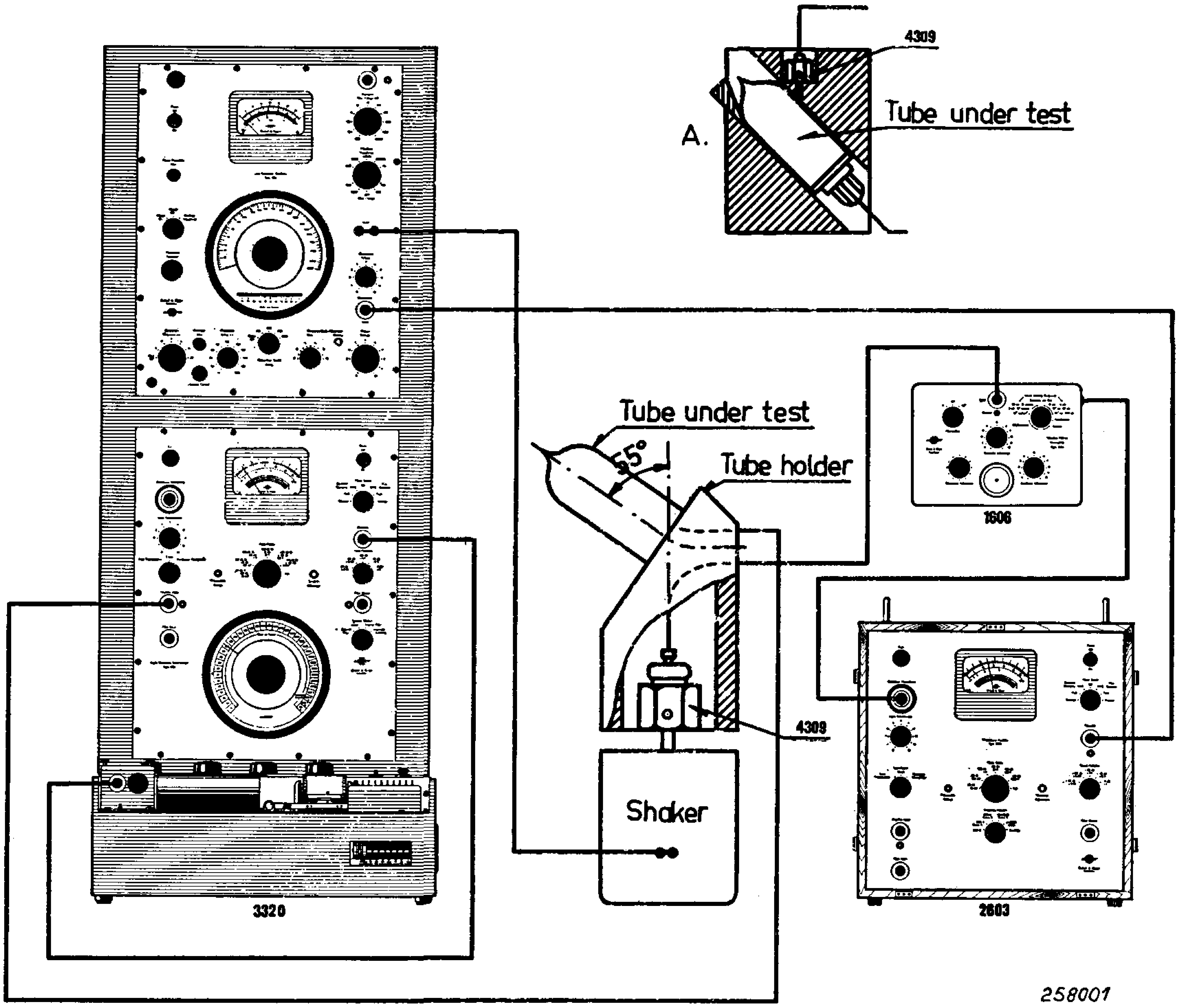


*Fig. 1. Measuring arrangement for the measurement of microphonics in a vacuum tube.*

is fed to the compressor input (regulating amplifier input) of the BFO to keep the vibration level constant. The vibration level is indicated on the meter of the Microphone Amplifier. The output voltage from the tube, i.e. the microphonic signal is fed to the ⅓ octave Spectrometer Type 2110 (the middle part of Type 3320) and from here to the Level Recorder Type 2304 (the lower instrument in Type 3320).

When the tube is placed in the tubeholder as shown in the set-up, the acceleration level of the tube socket is kept constant, and when placed as shown in the sketch A, the vibration level of the tube itself is kept constant. By means of the arrangement shown, a frequency analysis is automatically obtained. The motor in the Level Recorder drives the frequency sweep arrangement of the BFO and the filter switch arrangement of the Spectrometer synchronously, so that only that part of the microphonic signal which is of the same frequency (to within ⅓ octave) as the BFO frequency, is recorded on the preprinted, frequency calibrated recording paper on the Level Recorder. The measurements are carried out selectively to reduce the influence of the thermal noise on the recordings, and will be further explained in the following. Fig. 2 shows a frequency analysis of the microphonics from a tube type ECC 82.

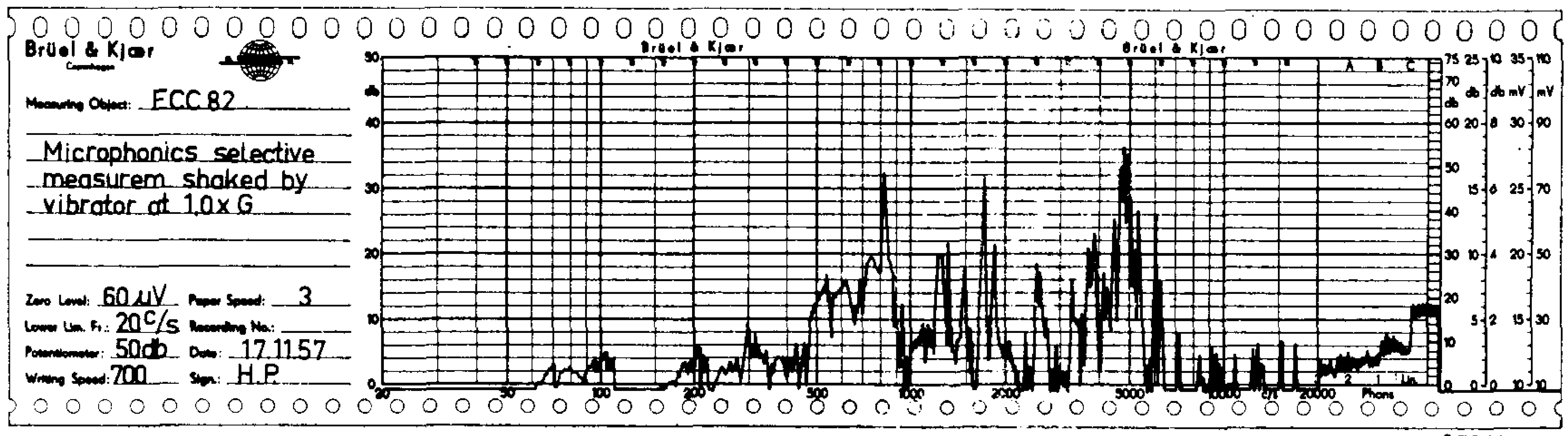


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*Fig. 2. Recording of the microphonics from a twin triode ECC 82 as a function of frequency. (Frequency sweep method, by use of vibrator).*

It is seen that many peaks are obtained in the recording. To be sure that the Level Recorder does not cut these off, the writing speed must be high and the frequency scanning speed low. By comparing different recordings with one obtained with a scanning speed 1/40 revolution/min. and a writing speed of 1,000 mm/sec, it was found that a scanning speed of 1/1.333 rev./min. and a writing speed of 700 mm/sec were satisfactory.

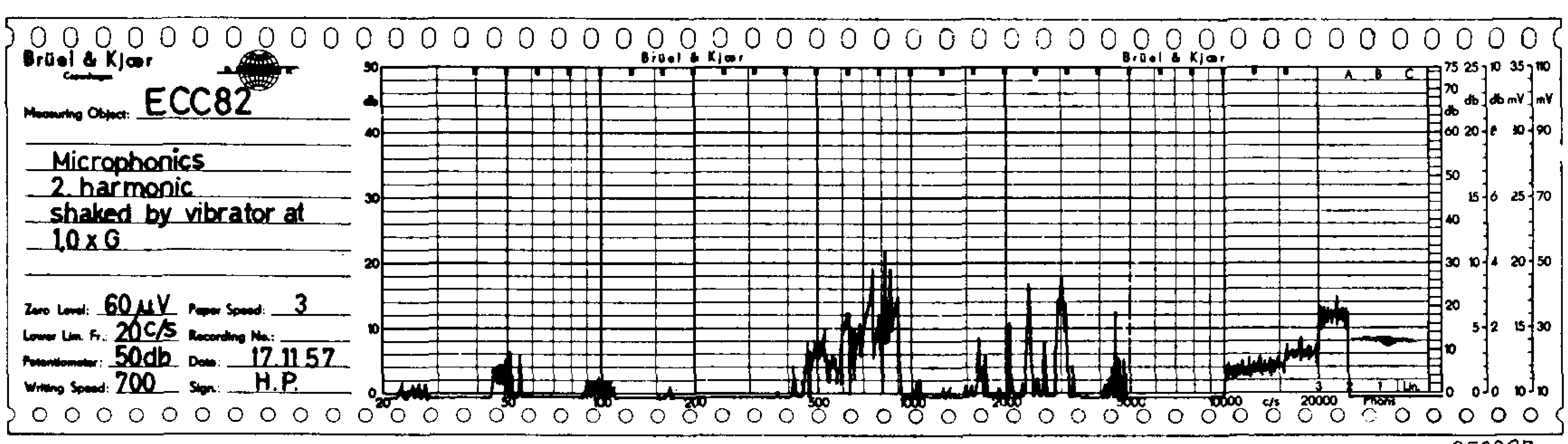


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*Fig. 3. Recording of the second harmonic of the microphonics of a tube type ECC 82.*

Under these conditions also the second harmonic is recorded (Fig. 3). By the second harmonic should be understood the contents of the frequency 2f, in the microphonic signal for an exciter frequency of f. The recording is carried out automatically by adjusting the filter switch of the Spectrometer to go one octave ahead of the frequency scale pointer of the BFO.

Although the noise level, by which is meant the output signal when the tube is in rest, is very small as shown in Fig. 4, the effect of the noise on the recordings, when non-selective measurements are carried out, is very big. This is seen in Fig. 5. The recording is obtained using the Spectrometer as a linear amplifier, i.e. with the filter switch in position "Lin-C". This position also corresponds to the recorded level to the far right on the recording in Fig. 4.

By comparing this level with the over-all noise level in Fig. 5 it is seen that both are 12 db re 60 $\mu$V. This shows that the disturbances really are noise and not microphonics.

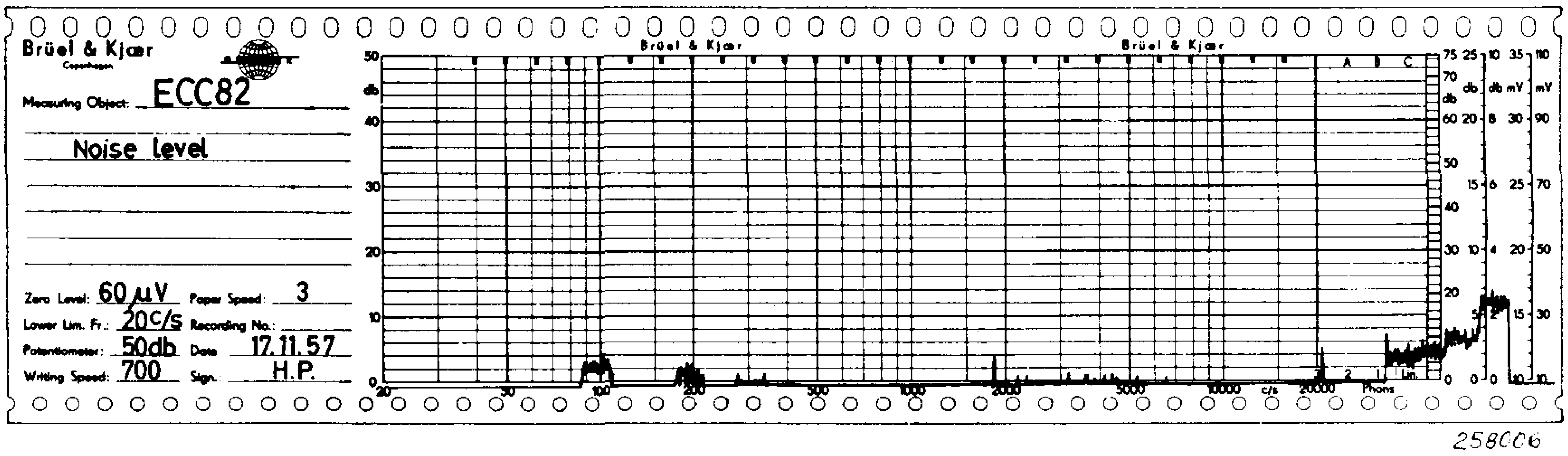


*Fig. 4. Frequency analysis of the noise from a tube type ECC 82.*

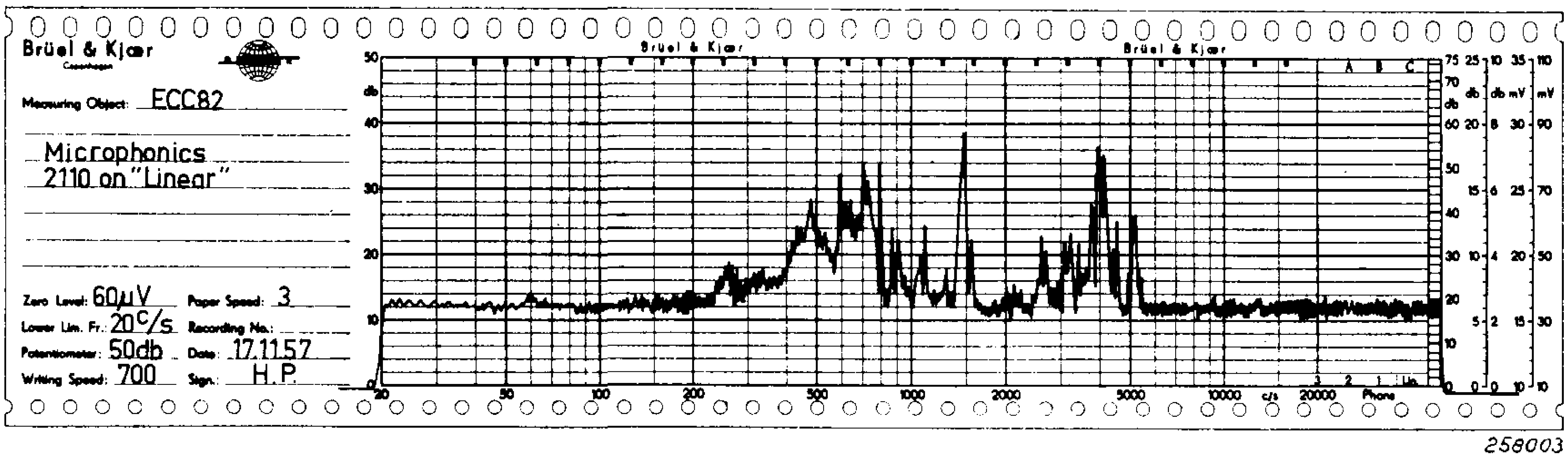


*Fig. 5. Microphonics of a tube type ECC 82 measured by means of the Spectrometer used as a linear amplifier.*

To establish the influence of an altered direction of the vibrating force, another analysis was made under exactly the same conditions as previously but for a 45° revolving of the tube on its longitudinal axis. The analysis obtained is shown in Fig. 6. Although the recording is very much like the one in Fig. 2, it is clearly noticed, that the revolving makes the electrodes oscillate in another way.

In Fig. 7 is shown an analysis of the microphonics of a tube type ECC 83. The difference between the two tubes is seen to be much greater than the difference between the two measurements on the same tube for a 45° revolving.

Another method for vibrating the table is to use a white-noise generator for excitation. In this way all the resonance peaks of the tube are excited at the same time, and the microphonics are simply read as a deflection on a voltmeter. For production control this must be said to be a very convenient

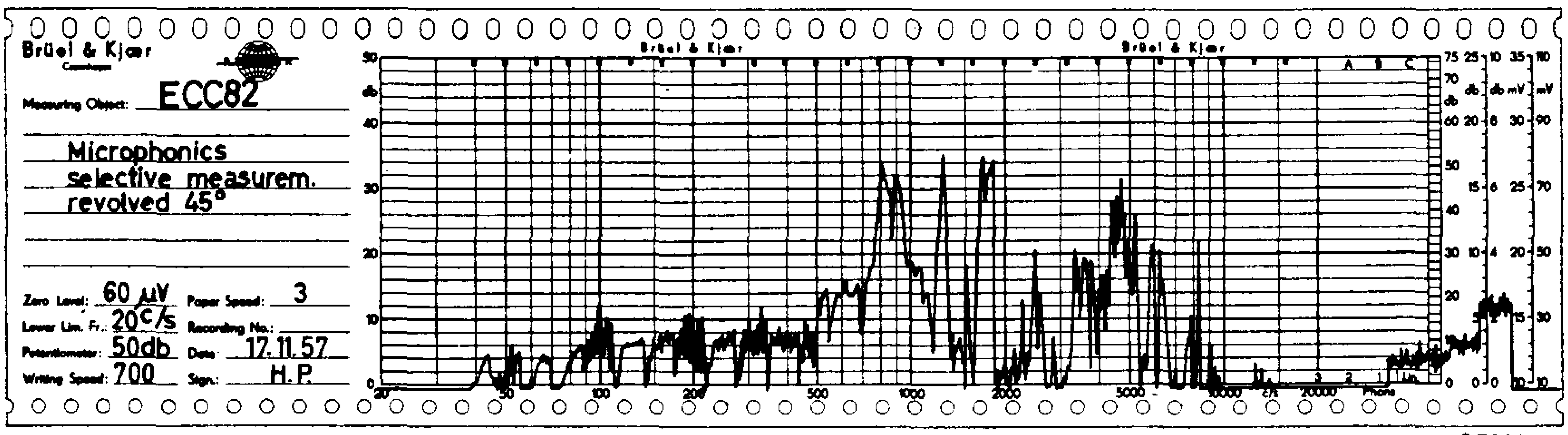

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*Fig. 6. Selective measurement of the microphonics from a tube type ECC 82 revolved 45° on its longitudinal axis respective to the position used for the recording in Fig. 2.*

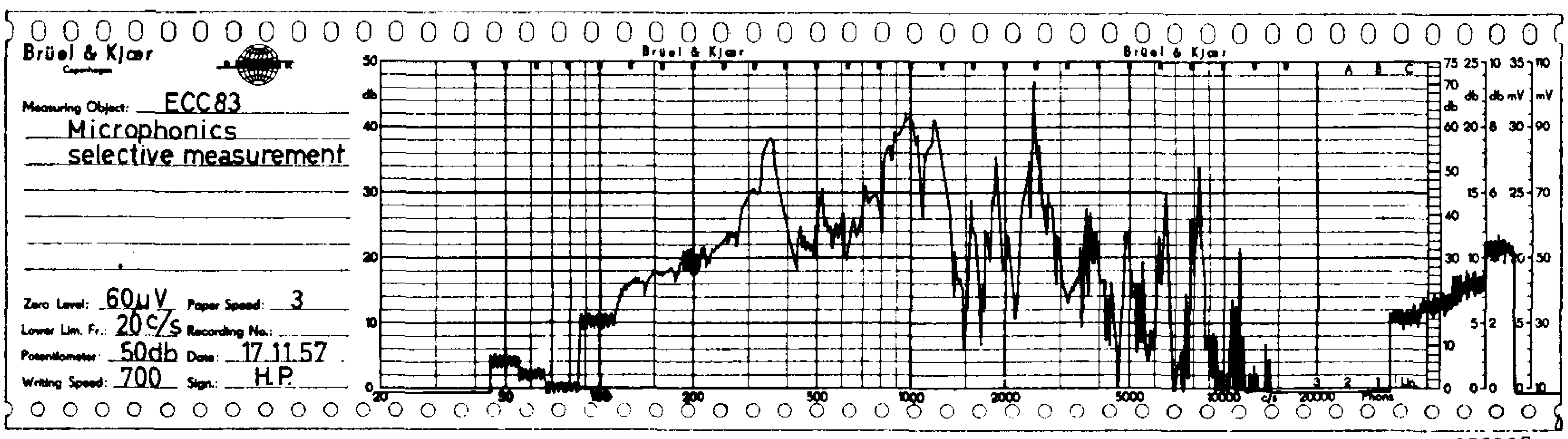

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*Fig. 7. Selective measurement of the microphonics from a tube type ECC 83.*

method, if only one figure is desired and no detailed analysis is necessary.
One of the draw-backs of this method is, however, that the frequency response of the vibrating table with load must be flat in order to excite all resonances with the same force. Normally the frequency characteristic of a shaker is, unfortunately, not flat, but shows peaks and more or less selective attenuations. Even for relative measurements of microphonics a shaker with a "bad" frequency characteristic is almost useless. Because the resonance frequencies of two tubes are not the same, a microphonic tube might be preferred to a less microphonic one when the choice is based upon white-noise measurements carried out by means of a "bad" shaker. That frequency (those frequencies) which gives the biggest contribution to the microphonic signal might be excited to a small degree only, and the total signal therefore be smaller than the signal from another, less microphonic tube which is excited right at the critical frequencies. The problems may be solved by inserting a compensating network, the frequency characteristic of which is the reciprocal characteristic of the shaker system, in series with the shaker. In this way the total frequency characteristic can be flattened, and reliable measurements carried out. In Fig. 8 is seen a

frequency characteristic (marked A) of a shaking system with no compensating networks. It is clearly seen that the designing of a correction filter would be rather complicated.

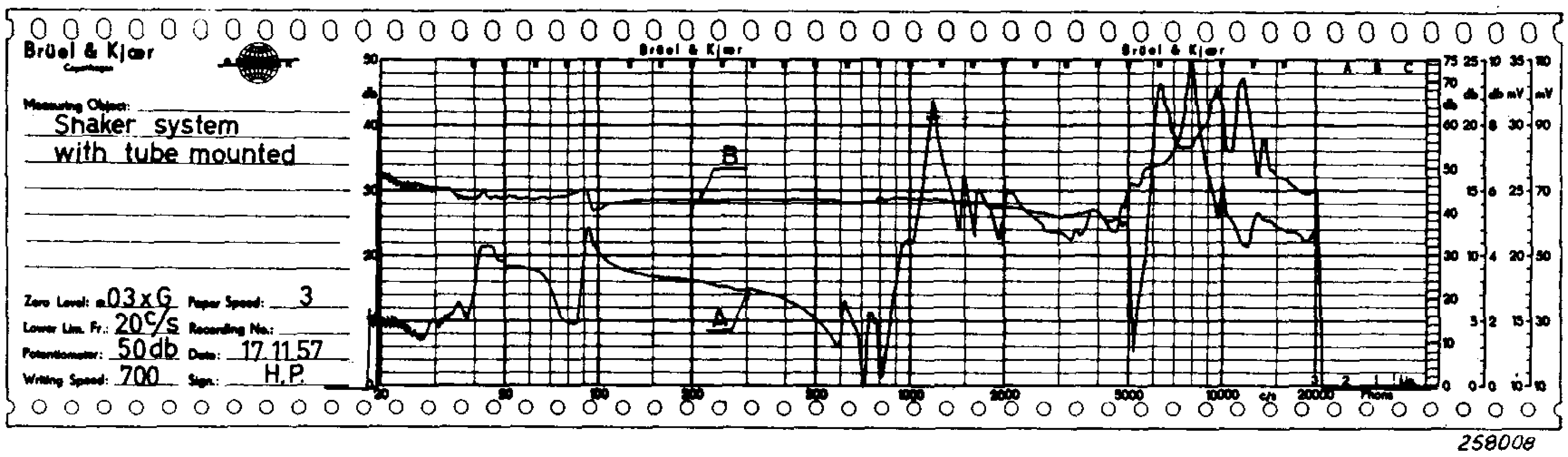



*Fig. 8. Frequency characteristics of the shaker system for two different load arrangements.*

However, the shape of the characteristic is also a function of the resonances of the load applied to the shaker. By arranging this load in a suitable way, a certain compensation can be obtained. A result is shown in Fig. 8 curve B, which is the frequency characteristic of the same shaker as A, but with a re-arrangement of the suspension of the tube holder. A frequency analysis of the acceleration of the table with the load so arranged when energized with white noise is seen in Fig. 9. This analysis is measured by means of the Spectrometer. Being a ⅓-octave analyzer, a recording of a pure white-noise signal analyzed by this instrument, must be a straight lined curve with a gradient of + 10 db per decade. The straight line is drawn, and the deviations from this ideal curve are clearly noticed. The increase at frequencies from 6 to 14 kc/s is due to the frequency characteristic of the shaker system.

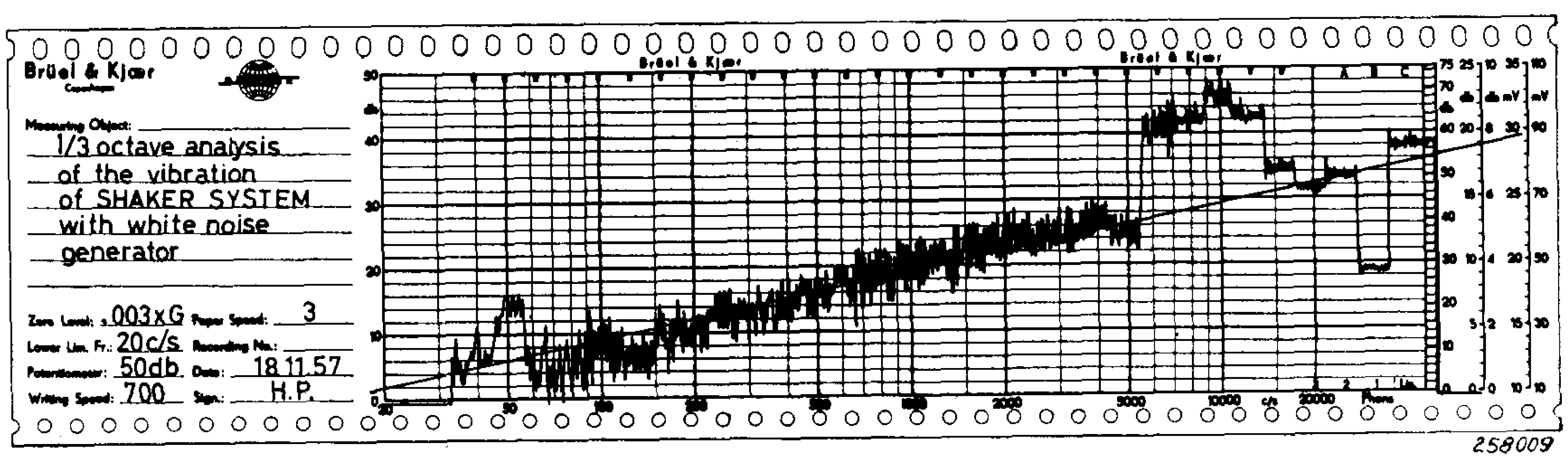



*Fig. 9. Frequency Analysis on 1/3 octave basis on the acceleration level of the shaker loaded according to curve B in Fig. 8, when energized by a white noise generator.*

In Fig. 10 is shown a frequency analysis of the microphonics measured by means of white-noise. It is seen that no pronounced peaks are developed, and that the lower frequencies are suppressed. Furthermore, the contents of frequencies from 7 kc/s to 15 kc/s is increased corresponding to an increased acceleration of approx. 14 db (Fig. 9). This causes the analysis give an unsatisfactory picture of the distribution of the microphonics on the different frequency bands. Then it is not to be expected either that the microphonic signal measured by an instrument with a linear frequency characteristic should be indicated correctly. Such a measurement is recorded in Fig. 11a. The recordings are made for 3 different vibration levels. As the potentiometer in use on the Level Recorder was a 25 db potentiometer, it is seen that the microphonic signal is almost proportional to the acceleration level. In Fig. 11a a linear frequency response is used for the Spectrometer, and in Fig. 11b the microphonics are weighted in a standardized weighting network. For tubes designed for sound reproducing equipments these levels might be of greater interest than the ones in Fig. 11a because they are the approximate levels felt by the human ear. In Fig. 12 is shown the measuring set-up used for these investigations.

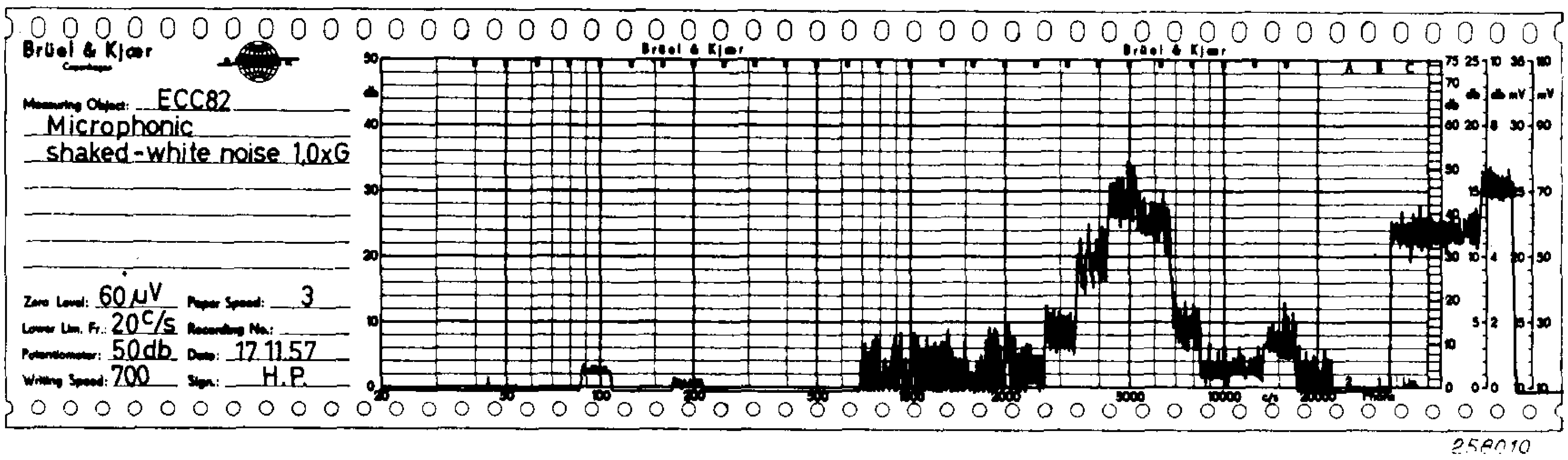
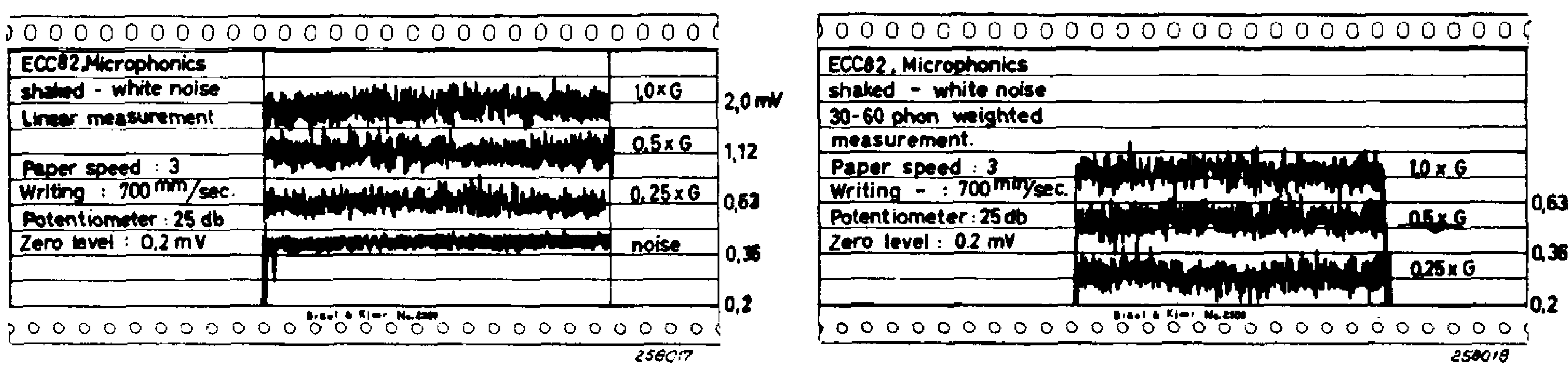



*Fig. 10. Frequency analysis of the microphonics from a tube type ECC 82 shaken by means of a vibrator energised from a white noise generator. (Random motion method).*




*a* *b*

*Fig. 11. Microphonic level of a tube type ECC 82 as a function of time, measured according to the random motion method by means of the Spectrometer used as*

*a. a linear amplifier*

*b. an amplifier with the standardized weighted frequency characteristic used for sound level measurement (ASA A, DIN 2).*

**Exciting by Means of Sound.**

Like the tests carried out by means of a shaker, this procedure also enables the measurements to be made according to the frequency sweep method

or the random motion method. Because the problems involved are familiar to the ones already outlined, only the special problems concerning the frequency sweep test are discussed.
The measurements are carried out as before, but with the shaker replaced by a loudspeaker producing the sound which "strikes" the tube under test and shakes it.
The first problem which arises is the demands which must be made on the test enviroments. The most well-defined acoustic conditions are obtained if the measurements are carried out in a free sound field (i.e. a sound field where no sound reflections are produced by the boundaries of the space). These conditions are practically present in the open air, where the sound

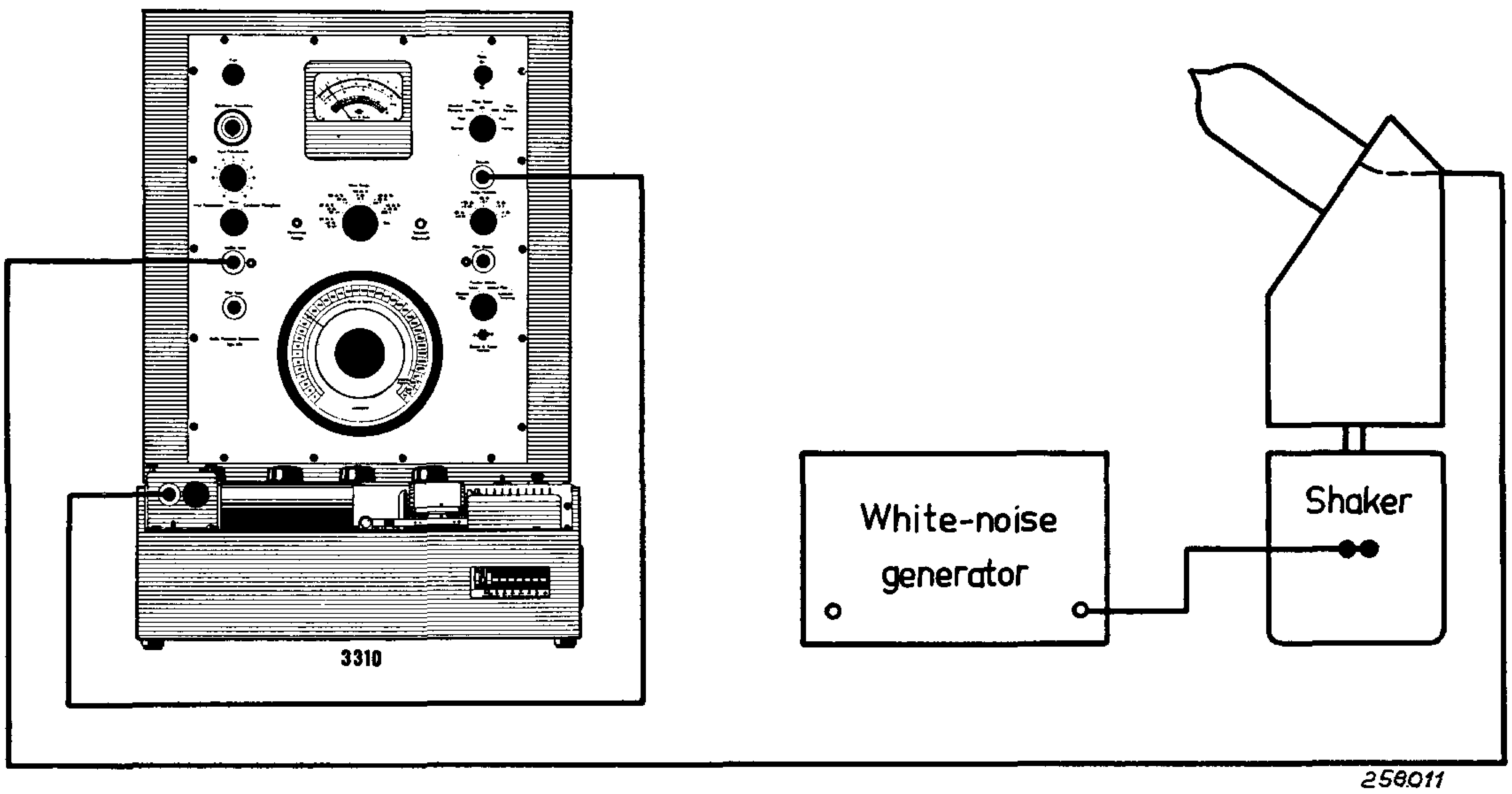



*Fig. 12. Measuring arrangement for tube testing by white noise.*

reflections from the earth are the only disturbing factors, or in an anechoic chamber, in which free field conditions can be obtained within a certain frequency range. For the measurements carried out by means of the measuring arrangement shown in Fig. 13, a chamber with anechoic qualities from 150 to 20ooo c/s was used. To be able to disregard the frequency characteristic of the loudspeaker, the sound level is kept constant by means of a regulating microphone. In the measuring arrangement the Condenser Microphone Type 4111 produces a reference signal proportional to the actual sound pressure at the Microphone diaphragm. Via the Microphone Amplifier Type 2603 this signal is fed to the compressor of the BFO feeding the loudspeaker. If the microphone and the tube are placed symmetrically in the sound field almost equal sound pressure conditions are present at the two places. In Fig. 14 is shown the frequency characteristic of the sound pressure at the regulating Microphone. The small "dips" occur in the curve because the measurements are carried out selectively by means of the Spectrometer. It is seen that good conditions are obtained from 200 c/s to 10 kc/s. In Fig. 15 is shown a frequency analysis of the microphonics from a tube type ECC 83 when shaken by a sound pressure of 115 db (curve A). This recording must be compared with curve B which shows the microphonics developed in the electrical components mounted directly on the tube socket. It is noticed that the microphonics at the higher frequencies and a great part of the microphonics below 1000 c/s are produced by the

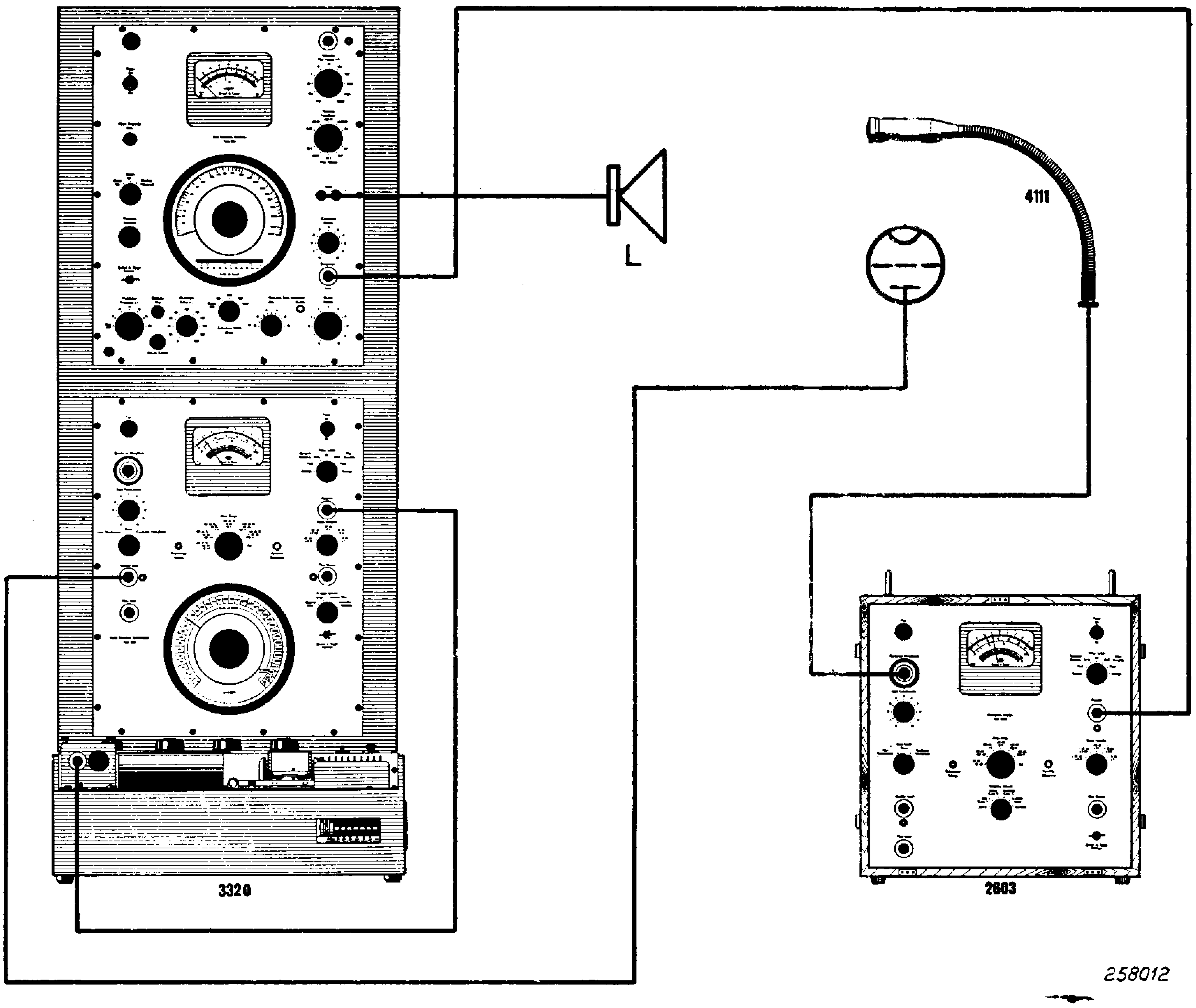



*Fig. 13. Measuring arrangement for measurement of the microphonics from a vacuum tube excited by means of sound according to the frequency sweep method.*

different components. If both the components and the tube are shaken simultaneously, it is therefore very important to check the microphonic qualities of the employed components from time to time. The best results are of course obtained, if the components are not shaken at all.
Another possibility is to carry out the measurements in a reverberent chamber. In this way the tube is excited from all sides simultaneously and higher sound levels are more easily obtained. The frequency characteristic of the loudspeaker must, however, be flat, because no automatic regulation by

means of a microphone is possible. As when used with white noise feeding, networks for compensation of the frequency characteristic must be introduced in the measuring arrangement.

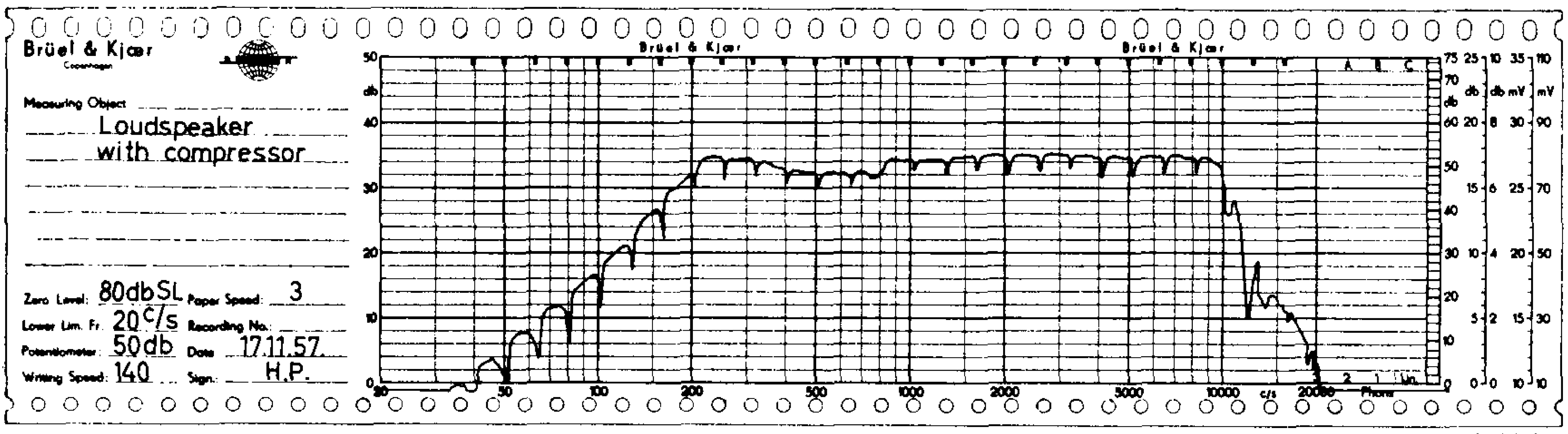


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*Fig. 14. Sound Level versus frequency at the regulating microphone in the set-up of Fig. 13.*

**Exciting by Tapping the Tube.**

The most simple way of checking a vacuum tube for microphonics is to knock on the tube by means of a small hammer or similar device, and then listen to the signal when amplified in an a.f. amplifier. However, little information is obtained in this way. Even if the signal is measured on a voltmeter, the result s very unsatisfactory which will be clear from the following.

From the spectrograms shown in the previous parts of this article it is seen, that the microphonics consist of frequencies in the entire a.f. range. It is, therefore necessary to shake the tube with the same force at all frequencies. That the spectrum of an infinitesimal pulse is continuous and with the same amplitude at all frequencies, is well known. In practice it is, however, impossible to produce a pulse of such a short duration, and as is seen in Fig. 16 the spectrum of a square pulse mainly consists of lower frequencies.

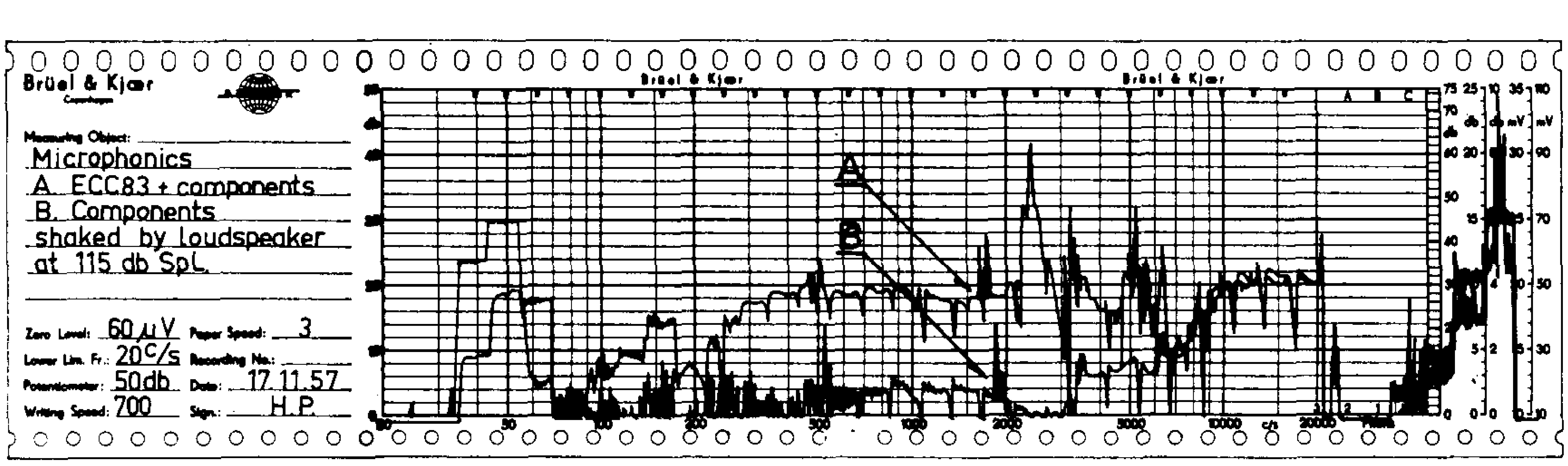

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*Fig. 15. Curve A. Microphonics of a tube type ECC 83 when shaked by means of sound according to the frequency sweep method.*
*Curve B. Microphonics of the electrical components used with the tube ECC 83.*

To find out which frequencies can be expected by a practical measurement, the shape and the duration of a single knock as a function of time should be known. If it is assumed that the shape is a square wave as shown in Fig. 16, the contents of higher frequencies are greater than for any other pulse shape with longer raisetime. The frequency distribution so obtained is, consequently, better than the one obtained in practice. To find the duration of the pulse the following experiment was made: By loading a capacitor through a resistor by means of a known d.c. voltage in that period of time in which the hammer and the tube touch each other, an average

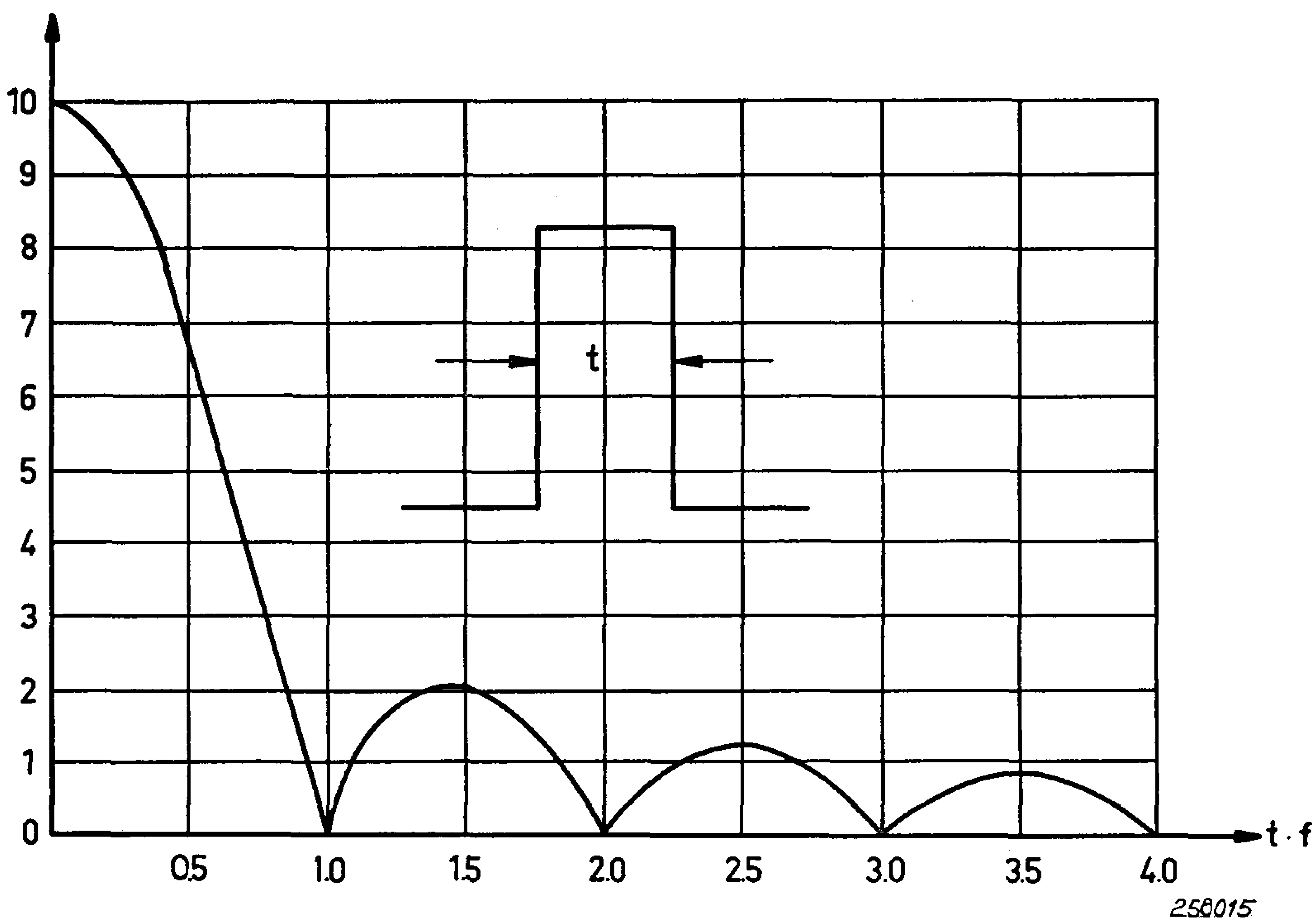


*Fig. 16. Frequency distribution of a square wave with a duration of t sec. The abscissae are given in the relative units t · f, where f is the frequency.*

duration of 50 msec. was found. This means that the first zero in Fig. 16 occurs at 20 c/s, the next at 40 c/s, the third at 60 c/s and so on. It is seen that the tube is only slightly excited at the higher frequencies, and at certain frequencies not excited at all. By tapping the tube with a series of knocks, the place of the zeros must shift a little, because the duration of the different tappings is not constant. The result is, that the distribution curve approaches a hyperbola, with a decrease of 20 db/octave. This means that the tube is shaken at 2000 c/s with a force that is only 1/10 of the force at 200 c/s but 10 times as great as that of 20000 c/s. So the microphonic signal obtained by tapping the tube only gives a very poor picture of the microphonic properties of the tube. It can be stated that the smaller the difference between the actual frequency distribution and a white noise distribution is, the better are the results obtained. By making the tapping more random, the frequency spectrogram may be flattened a little. This can be obtained by shaking the tube by means of a jet of water. The jet of water should preferably consist of drops which strike the tube at different intervals, and not of a laminar stream. The drops act on the tube with a force, the frequency spectrogram of which is seen on Fig. 17. As the spectrogram is recorded by means of the ⅓ octave A.F. Spectrometer, it is seen that the force has a white noise distribution for frequencies below 300 c/s, a — 10 db/decade slope from 200 to 1500 c/s, and finally a decade slope of approx. — 25 db for frequencies higher than 1500 c/s. Using this method more reliable results are obtained than by tapping the tube by a hammer, but the results do not give the correct value for the microphonics.

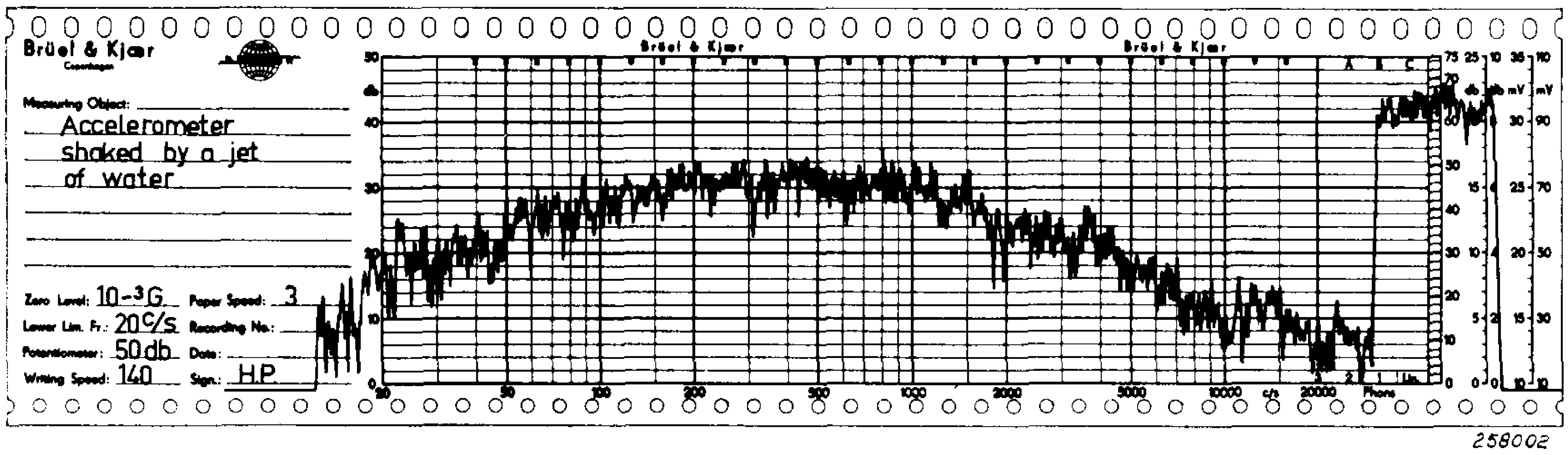


*Fig. 17. Frequency analysis of the acceleration of a tube exposed to a jet of water. Analyzed by means of the* $^1/_3$ *Octave Spectrometer.*

## Conclusion.

Which one of the methods here described should be preferred in the different cases when the microphonics of a vacuum tube are to be measured, depends on the purpose of the measurements. If detailed information on the behaviour of the tube is wanted for research purposes the frequency sweep method is preferable. Also for production control of specially selected high quality tubes, this method, although it is more time consuming than the random motion test method should be chosen, because it gives a very exact picture of the resonance curves. For normal, low microphonic tubes the random motion test with shaker is most convenient. However, to judge properly the results obtained from such a test, the relationship between the random response of the tube and its response to the frequency sweep test should be established once and for all for each new tube type to be tested.

For other tubes with relatively high microphonic level any of the methods may be used, when the tolerances on the measured results are first considered.

## Litterature.

**Valkó, Ivan Peter:** Eine neue Methode zur Untersuchung der Röhrenmikrophonie. Hochfrequenz-technic und Elektroakustik. Band 65, Heft 2, September 1956, and Band 65, Heft 4, January 1957.

# News from the Factory.

**Deviation Bridge Type 1503.**

The new Deviation Bridge Type 1503 for testing Resistors, Capacitors, and Inductors operates at a frequency of 100 c/s. It has been specially designed for production control of electrolytic capacitors, and constitutes together with the Deviation Bridges Type 1504 (1 kc/s), Type 1505 (10 kc/s), and Type 1506 (100 kc/s) a complete line of test instruments for electrical components.

*Fig. 1. Photo of the Deviation Bridge Type 1503.*

The following range of components can be tested:

Inductances from 2 mH to 2000 H.
Capacitors from 500 $\mu\mu$F to 2000 $\mu$F.
Resistors from 1 $\Omega$ to 30 M$\Omega$.

Four calibrated, interchangeable scales are supplied with the instrument:

| Impedance deviations: | Phase angle deviations: |
|---|---|
| $-$ 1.5 % to $+$ 1.5 % | $-$ 1.5 $\times 10^{-2}$ to $+$ 1.5 $\times 10^{-2}$ radians |
| $-$ 7 % to $+$ 8 % | $-$ 7 $\times 10^{-2}$ to $+$ 7 $\times 10^{-2}$ radians |
| $-$25 % to $+$ 35 % | $-$25 $\times 10^{-2}$ to $+$ 25 $\times 10^{-2}$ radians |
| $-$50 % to $+$ 100 % | $-$80 $\times 10^{-2}$ to $+$ 80 $\times 10^{-2}$ radians |

Furthermore, two blank scales for special applications of the instrument are also included.

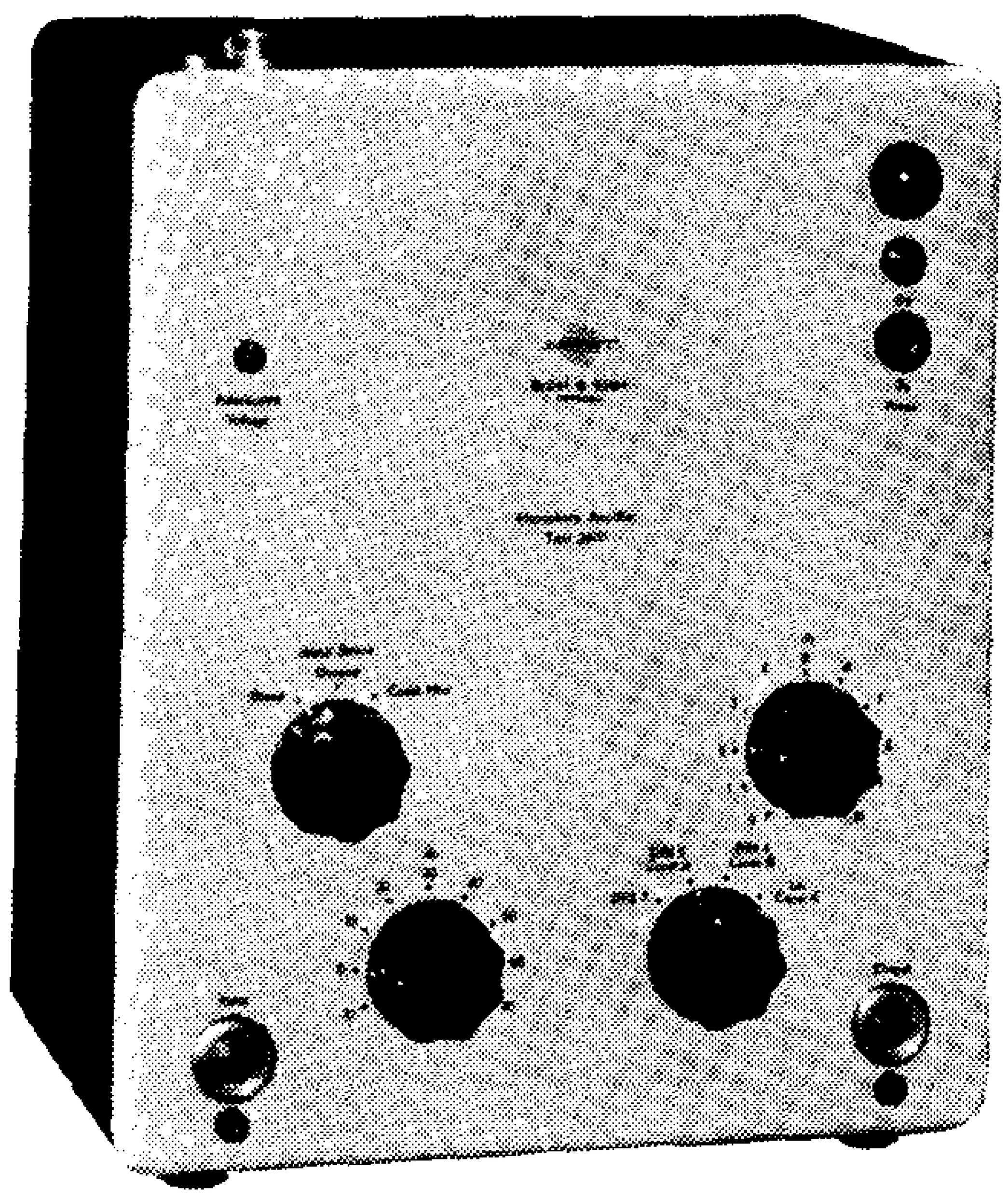

*Fig. 2 Photo of the Microphone Amplifier Type 2605.*

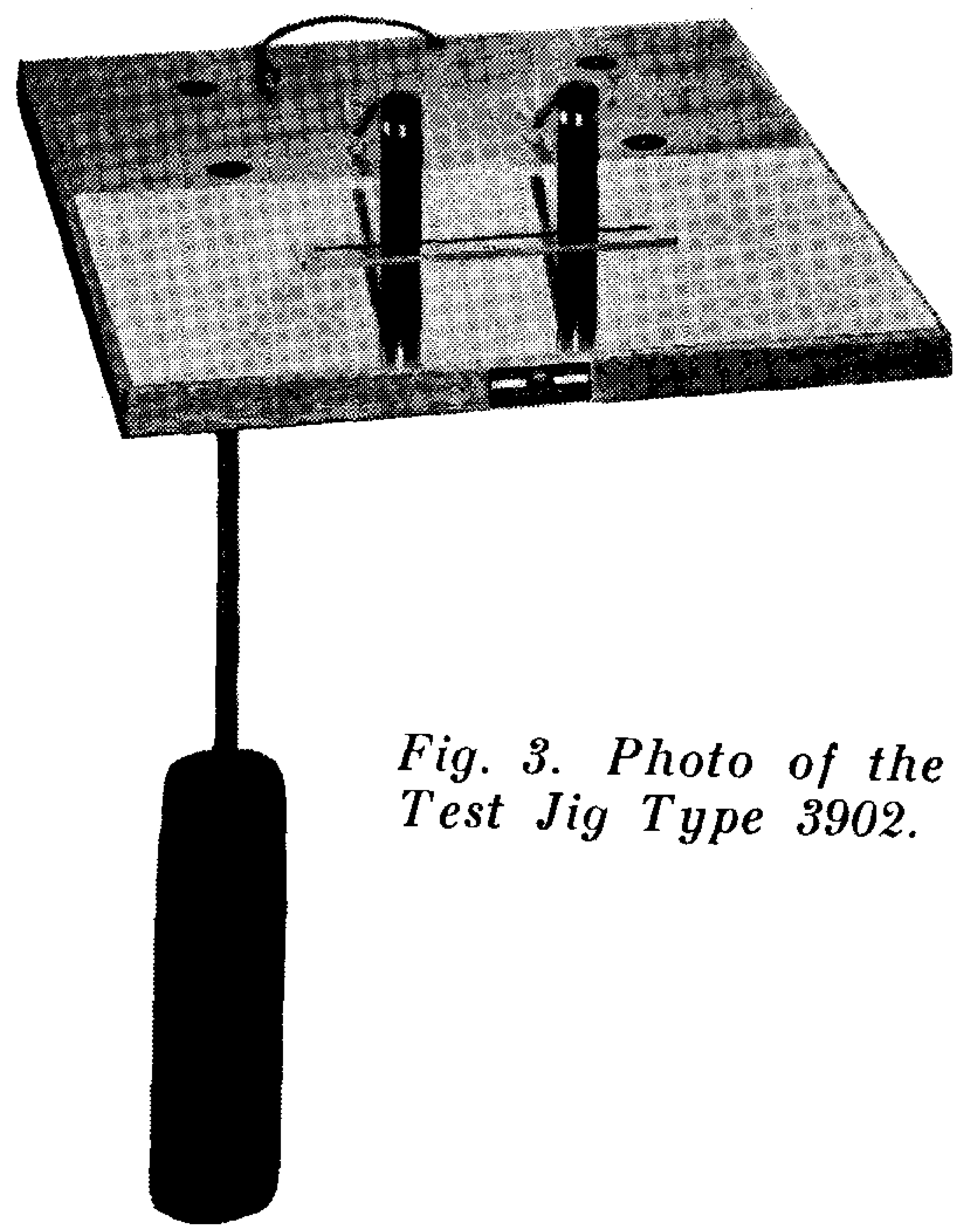

*Fig. 3. Photo of the Test Jig Type 3902.*

**Microphone Amplifier Type 2605.**

Type 2605 is a redesign of the Microphone Amplifier Type 2601, and features the following improvements:

1. The output impedance is decreased to 150 $\Omega$ (the output impedance of Type 2601 is 30 k$\Omega$).
2. The polarization voltage for the Condenser Microphone has been made adjustable in the range 150 to 250 volts.

**Test Jig Type 3902.**

Type 3902 is a less expensive version of the Test Jig Type 3901, used for production control of Resistors, Capacitors, and Inductors in connection with one of the Deviation Bridges Type 1503, 1504, 1505, or 1506. Type 3902 is supplied with one knee-operated lever for contact operation only, whereas the lever for the "Impedance/Phase angle" switch is omitted.

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