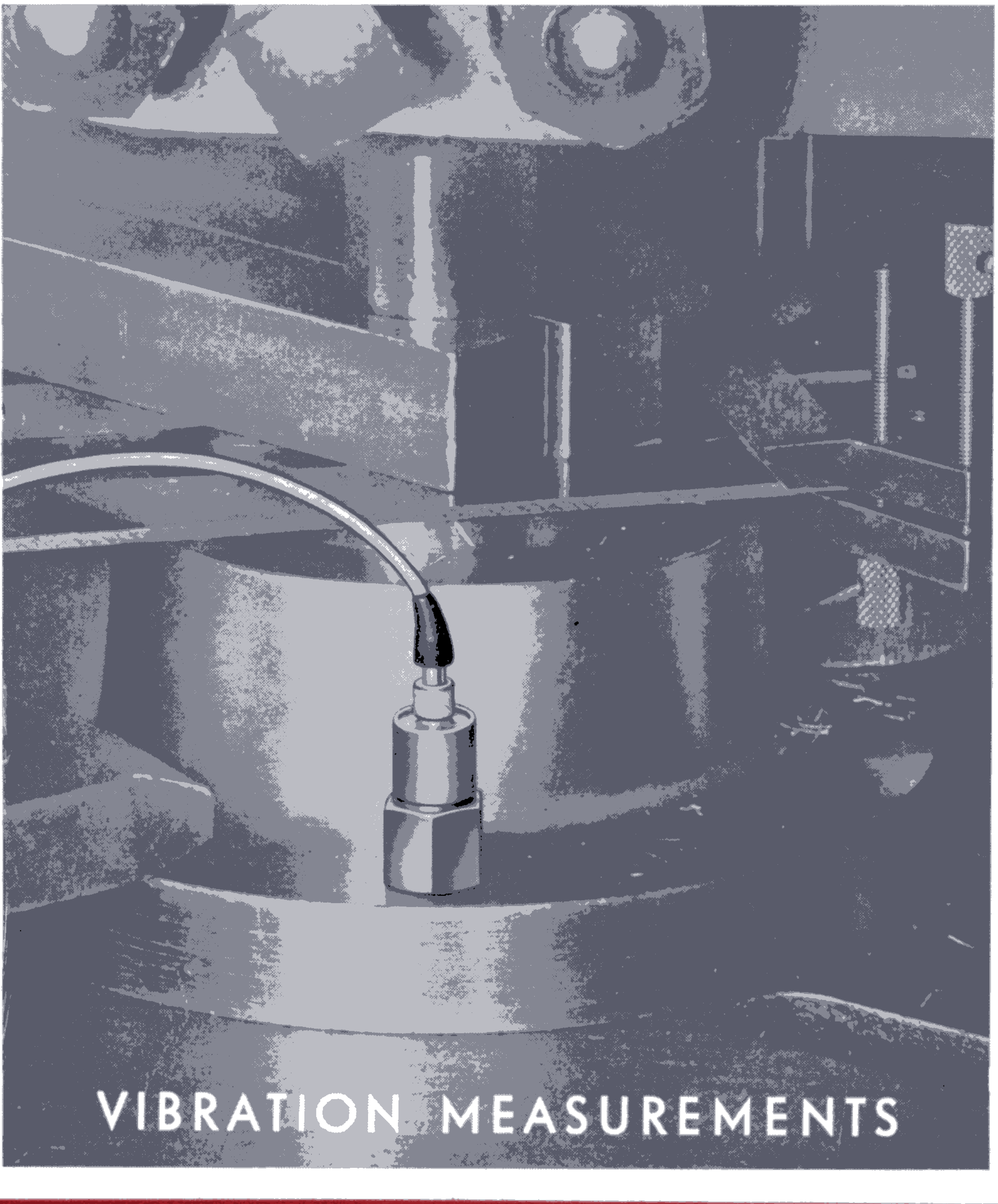
Brüel & Kjær

Technical Review

Teletechnical, Acoustical and Vibrational Research



No. 4 October 1956

TECHNICAL REVIEW

No 4 - 1956

Reprint: October 1960

CONTENTS

Electrical Measurement of Mechanical Vibrations.

By Jens T. Broch M. Sc.

The evaluation of measured results obtained when electronic measuring equipment is used for the measurements of mechanical vibrations may sometimes cause difficulties because so many factors are involved in these types of measurements. Both the frequency response of each individual instrument employed in the measuring system and the effect of long connecting cables will influence the meter-reading. When exact results are desired, the separate adjustment of each instrument must also be considered, and finally the meter-reading will depend upon the type of rectifier used in the measuring amplifier. It is thus of the greatest importance when complex vibrations are considered to be able to determine the effect of these factors, and in this article a complete vibration measuring and recording system is described and discussed. Special attention is given to the indicating meter circuit to emphasize its importance when complex signals are measured.

In modern design and maintenance of mechanical constructions it is of the utmost importance to be able to determine the magnitude and frequency of vibrations occuring at different places in the structure when it is subjected to dynamic forces. Not only is it possible from the measurement of vibrations to apply an effective insulation technique and thus reduce the external effect of the vibrations to a minimum, but quite often the measurement of vibrations enables the detection of faults in rotating machinery to be made.

Recent developments of mechanical-electrical transducers, together with reliable and sensitive electronic measuring equipment has made it possible to measure the properties of mechanical constructions with a high degree of accuracy. This measuring technique has now become an important factor in the field of development.

In the following the problems arising when electronic measuring equipment is used for the measurement of mechanical vibrations will be discussed with special regard to the Brüel & Kjær vibration measuring systems.

The internal stress which the object or construction experiences when subjected to mechanical forces may be determined by conventional strain gauge measurements.

The external effects, however, must be measured by means of another type of mechanical-electrical transducer, and when the forces applied are of dynamic character it is now normal to employ vibration pick-ups.

As the name implies the vibration pick-up is designed for the measurements of vibrations.
Normal vibration pick-ups have a flat frequency response ranging from 2—5 c/s and up to some kc/s. (The frequency range of the Accelerometer Type 4309 is 2 c/s—approx. 30 kc/s.)

There are three variables which are of interest in a vibrating system. The acceleration, the velocity and the displacement.
These variables are connected through the well known relationships:

$$v = \frac{\delta s}{\delta t} \quad \text{and} \quad a = \frac{\delta v}{\delta t} = \frac{\delta^2 s}{\delta t^2}$$

where s is the displacement, v the velocity and a the acceleration.
Using an electronic measuring equipment in connection with a vibration pick-up it is not normally essential which of the three quantities are actually measured by the transducer, because the remaining quantities can be found by electronic differentation or integration.
Due to the fact that the resulting force is proportional to the acceleration of the system a transducer which gives an output proportional to this quantity will, however, be the most convenient one to use in vibration measurement.
This special type of vibration pick-up is called an Accelerometer.
The principle of operation, as well as some constructional details of modern accelerometers employing piezo-electric materials as the mechanical-electrical transducing element are described in T. R. nr. 2. 1955, and will not be dealt with here.
When measurements are carried out on mechanical constructions employing an accelerometer several problems occur with respect to the signifiance of the result indicated by the deflection of the indicating instrument.
The sensitivity and frequency response of the Accelerometer given by the manufacturer refer to certain operating conditions which are determined by the test-set-up employed in the factory. When used in the field the conditions

may not be the same as the one used for testing the Accelerometer in the factory, and when exact measurements are required this must be taken into account and corrected for.

First af all the frequency response of the total measuring arrangement is determined by the "weakest link in the chain", i.e. that part of the equipment having the highest, low-frequency cut-off determines the lower limit of the frequency response. Similarly, the part which shows the lowest, high-frequency cut-off determines the upper limit of the response.

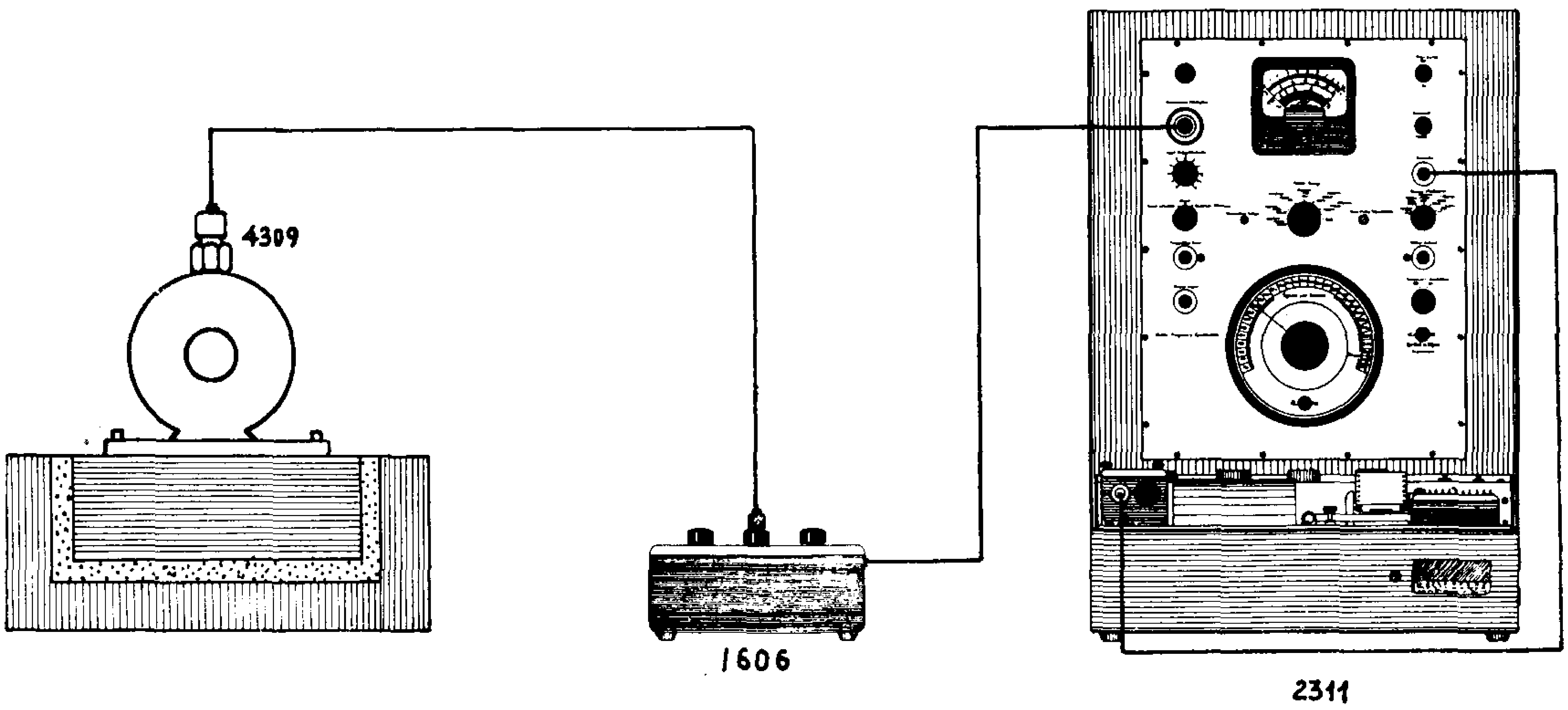


Fig. 1. Measuring arrangement for vibration measurements on a motor.

A typical measuring arrangement employing the Accelerometer Type 4309, the Vibration Pick-up Preamplifier Type 1606 and the Audio Frequency Spectrum Recorder Type 2311 is shown in fig. 1. (The Audio Frequency Spectrum Recorder consists of Spectrometer Type 2109 and Level Recorder Type 2304, the instruments being mechanically built together in one unit.) The frequency response of this complete measuring set-up is shown in fig. 2. The frequency characteristic shown is a typical response curve measured in the laboratory with the Preamplifier Type 1606 switched to measure the acceleration of the vibrations, and adjusted to give 0 db amplification. A low-noise connecting cable with a length of 1,2 m was used to connect the Accelerometer to the Preamplifier, and the Preamplifier itself was directly connected to the input of the Spectrum Recorder Type 2311.

A brief analysis of the "standard" measuring arrangement shown in fig. 1 will clearly indicate the importance of the different components.

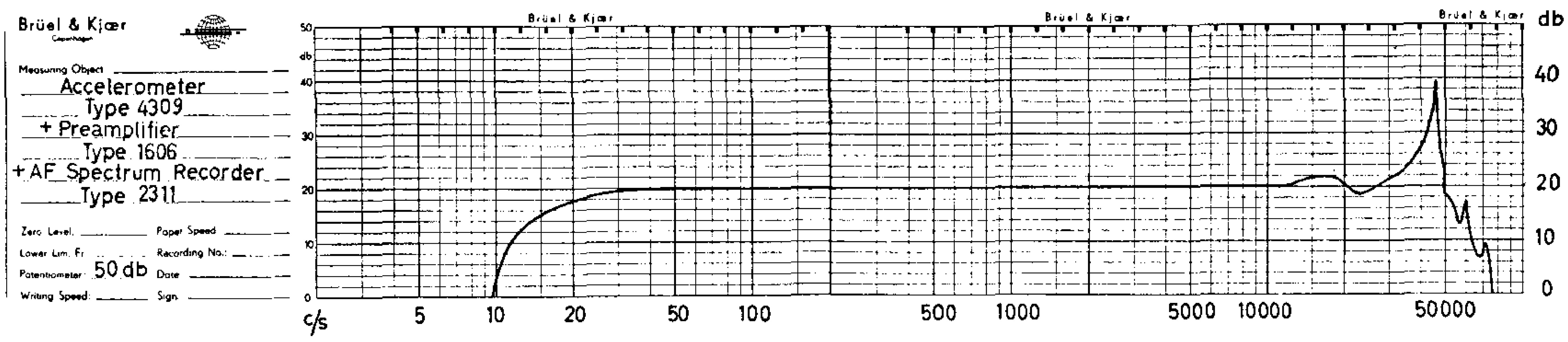


Fig. 2. Frequency response
of the measuring arrangement shown in fig. 1.

Starting with the Accelerometer Type 4309 fig. 3 shows a typical frequency characteristic of this instrument measured as the open-circuit voltage across

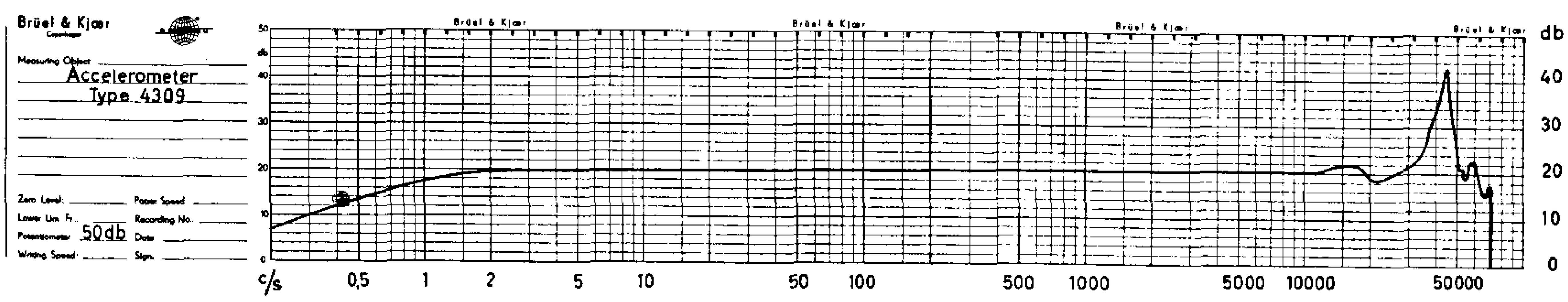


Fig. 3. Frequency characteristic
of the Accelerometer Type 4309.

its output terminals. In the stiffness-controlled range of the instrument, i. e below its mechanical resonance, the equivalent diagram of the accelerometer

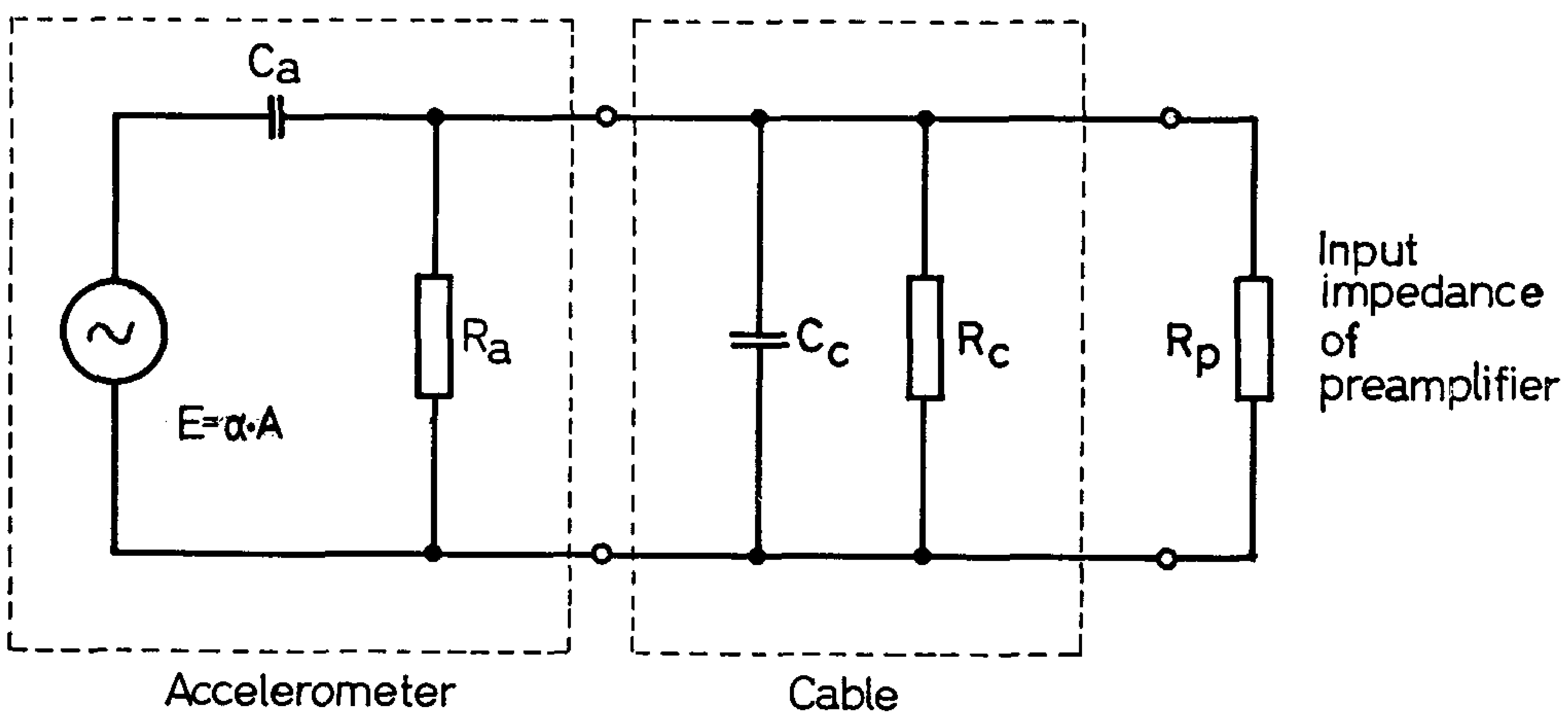


Fig. 4. Equivalent circuit
of an Accelerometer when connected to the measuring instruments.

will be as shown in fig. 4 with a generator, the output voltage of which is directly proportional to the acceleration, in series with a capacitor C_a and loaded with the insulation resistance of the accelerometer itself R_a.
The low-frequency cut-off of the accelerometer itself is determined by these constants. Loading the output of the accelerometer with the input impedance of a measuring amplifier reduces the value of R, and raises the low-frequency cut-off of the system. It is therefore of importance to use an amplifier with a high input impedance. The input impedance of the Preamplifier Type 1606 is > 40 MΩ for any setting of its sensitivity control, and when the Accelerometer Type 4309 is connected to this amplifier via the "normal" connecting cable the low-frequency characteristic will be as shown in fig. 5.

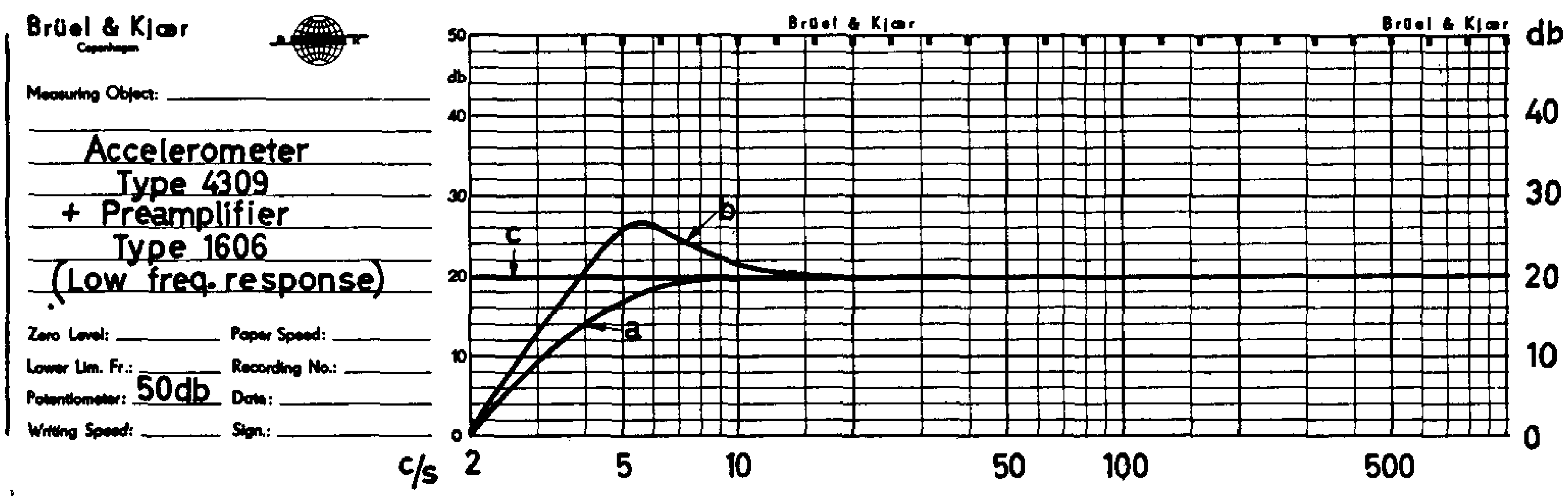


Fig. 5. Low frequency response of the Accelerometer Type 4309 when connected to the Preamplifier Type 1606.
Curve a): Sensitivity control of the Preamplifier in position max. (amplification approx. 40 db).
Curve b): Sensitivity control of the Preamplifier in position min. (amplification 0 db).
Curve c: Low frequency response of the Preamplifier itself.

Before stating the high frequency limit of the "flat" frequency response the remaining components of the measuring equipment will be discussed.

If measurements are to be carried out at places situated far away from where the indicating (or recording) equipment is placed it is necessary to employ long connecting cable. To influence the sensitivity and frequency response of the measuring arrangement to the least possible degree utmost care must then be shown.
An extension of the cable connecting the accelerometer to the preamplifier will influence the sensitivity of the set-up to a high degree. This due to the capacitance of the cable. From the equivalent diagram of fig. 4 is seen that a capacitive voltage division takes place between C_a and C_c, and the input voltage to the preamplifier is thereby reduced.

Furthermore, the low-frequency cut-off of the set-up will also be influenced, and using the symbols of fig. 4, the cut-off frequency will be:

$$f_o = \frac{1}{2\pi R \cdot C}$$

where C is the parallel combination of Ca and C_c, and R is the parallel combination of R_a, R_c and Rp.
This effect may be used to extend the measuring range downwards when it is desired to measure at extremely low frequencies and when a loss in sensitivity can be tolerated. Normally, however, the effect of the cable upon the frequency characteristic will be of no importance, and only the loss in sensitivity must be taken into account.
The Accelerometer Type 4309 has an internal (clamped) capacity of approx. 700 pF, and for a cable of approx. 60 pF/m the relationship between the length of cable and the decrease in sensitivity is shown in fig. 6.

A better solution to the problem is to use a long connecting cable between the preamplifier and the indicating amplifier.
Using the Preamplifier Type 1606 extension cables of the Type 4114 are available in lengths of 10 m, and several lengths may be coupled together. The Preamplifier should then be placed in the immediate vicinity of the measuring point, and connected to the indicating amplifier via Extension Cables 4114.

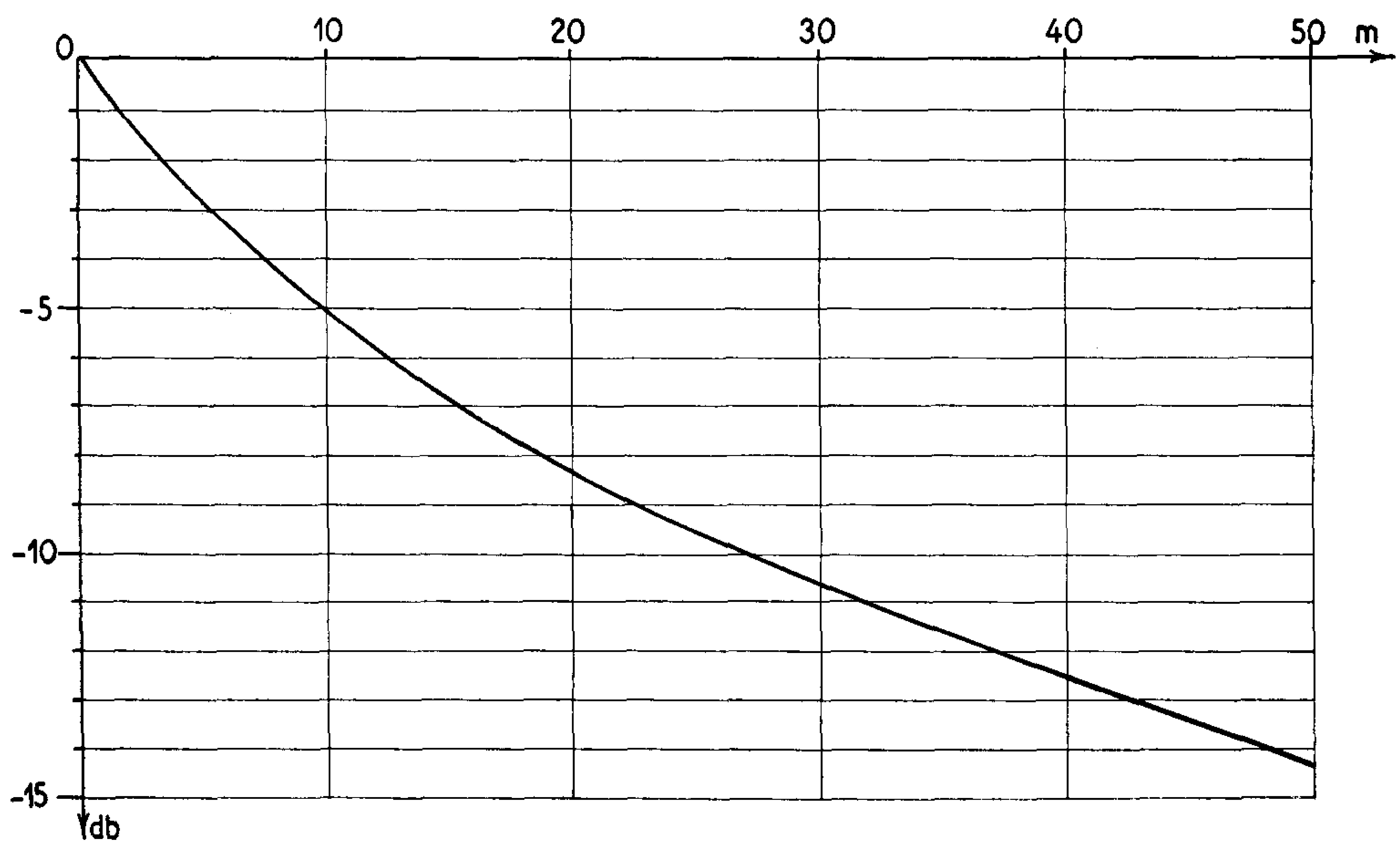


Fig. 6. Reduction in sensitivity when the Accelerometer Type 4309 is connected to the Preamplifier via a measuring cable with a capacity of approx. 60 pF/m.

The Preamplifier Type 1606 is a two-stage amplifier supplied with a heavy negative feedback to ensure a high input impedance. The amplification is varied by varying the amount of negative feed-back, and the frequency characteristic of this amplifier will therefore depend upon the position of the sensitivity control, see fig. 5 and fig. 7.

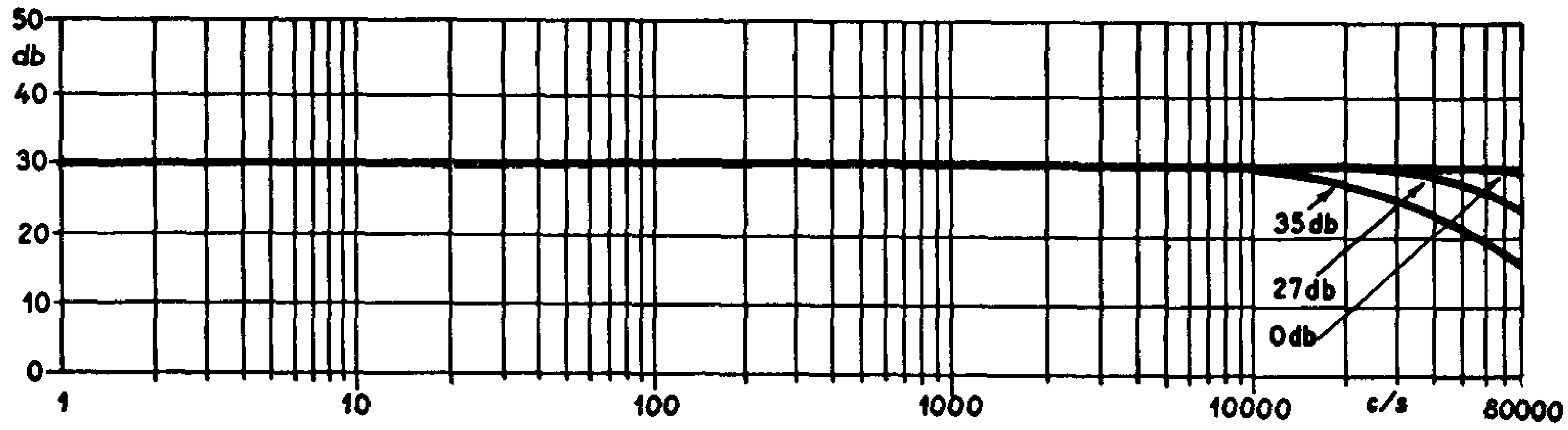


Fig. 7. Frequency response
of the Preamplifier + several lengths of
high frequency cut-off upon the position of the sensitivity control is clearly noticed, and is indicated by the different amount of amplification obtained for various positions of the control knob.

Fig. 7 shows the frequency characteristic of the Preamplifier and the different amount of amplification corresponding to different positions of the sensitivity control are indicated in the figure.
The Preamplifier also contains the integrating networks necessary for the measurement of the velocity and displacement of the vibrations considered when an accelerometer is connected to its input, and a small vibrator, used for calibration of the accelerometer.

When the Preamplifier is adjusted to give 0 db amplification the insertion of Extension Cables Type 4114 between the Preamplifier and the indicating amplifier, as mentioned above, will neither influence the sensitivity nor the frequency characteristic of the measuring arrangement, even with a total cable length of up to 100 m, see fig. 8.

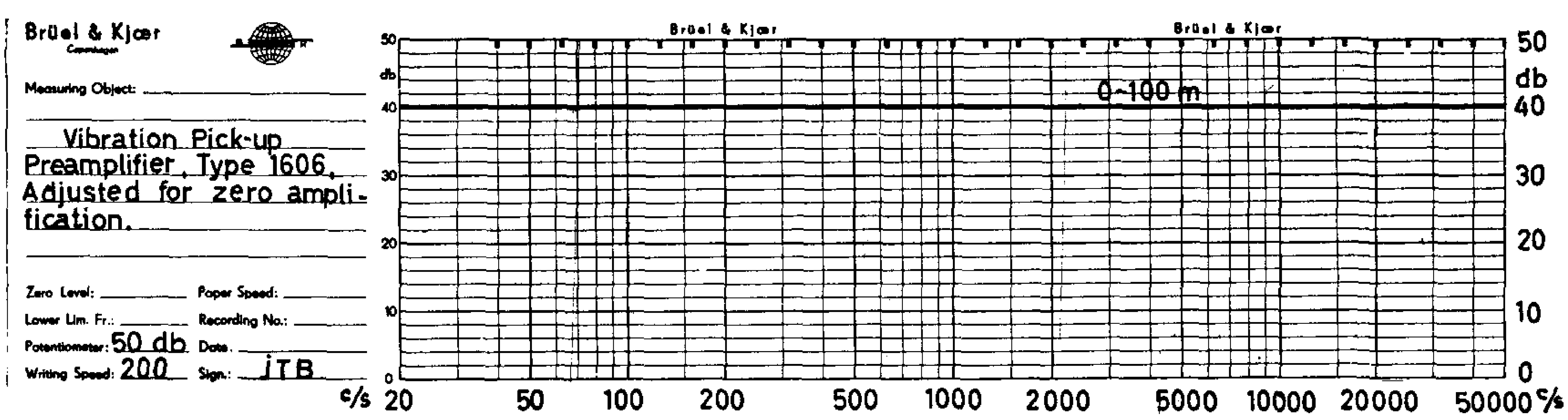


Fig. 8. Frequency characteristic
of the Preamplifier + several lengths of Extension Cable Type 4114
Preamplifier Type 1606 adjusted to give 0 db amplification

However, when the Preamplifier is set to max. amplification the influence of the Extension Cable is clearly noticed, fig. 9.

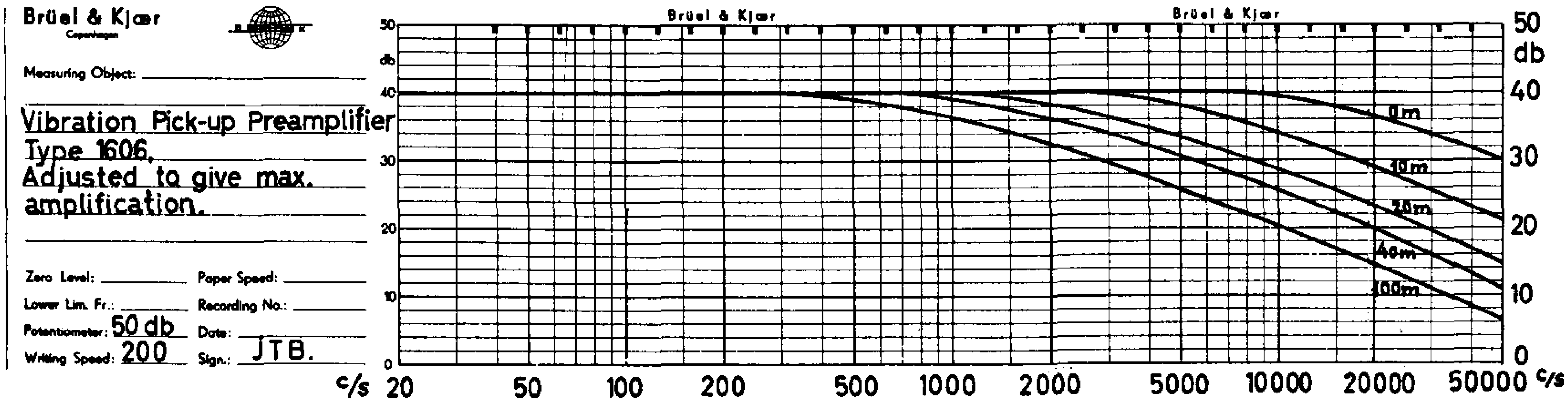


Fig. 9. Frequency characteristic
of the Preamplifier + several lengths of
Extension Cable Type 4114.
Preamplifier Type 1606 adjusted to give max. amplification
(approx. 40 db).

In the measuring arrangement shown in fig. 1 the Audio Frequency Spectrum Recorder Type 2311 was used as indicating amplifier. Other instruments such as the Microphone Amplifier Type 2602 or the Frequency Analyzer Type 2105 may of course also be used for this purpose, either alone, whereby the measured result is indicated on the instrument meter, or in conjunction with the Level Recorder Type 2304, whereby a written record of the result is obtained.

Employing the Spectrum Recorder as indicating amplifier enables the measurements to be carried out selectively which is a great advantage when complex vibrations are measured.

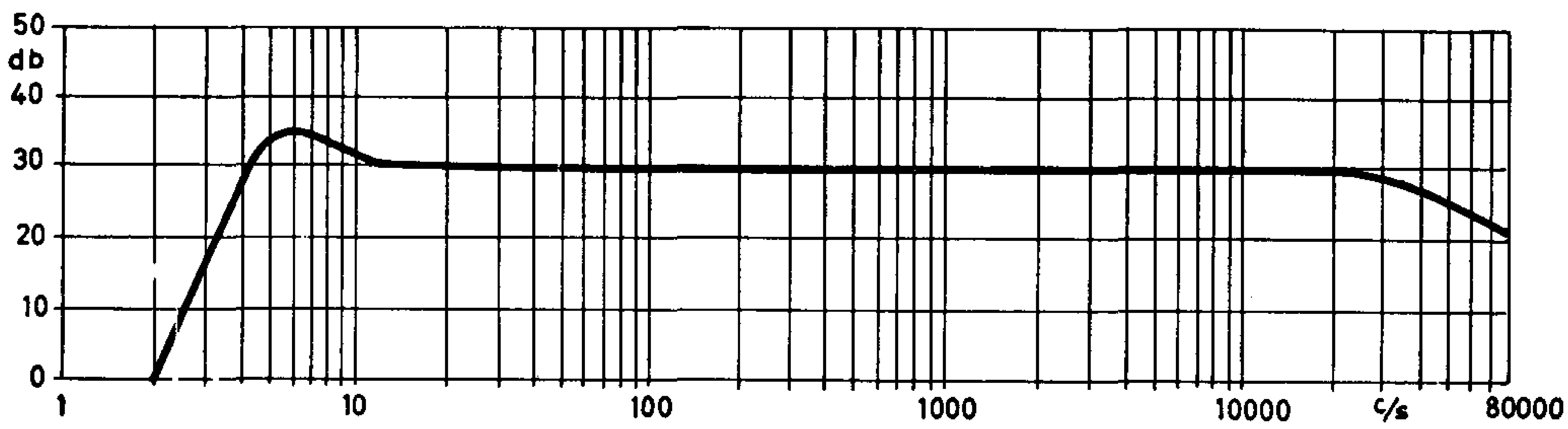


Fig. 10. Frequency response
of the Spectrometer Type 2109.

A typical frequency response of the Audio Frequency Spectrometer Type 2109 when switched to position "Lin." (linear) is shown in fig. 10. Allthough the instrument is only guaranteed to show a flat frequency response from 20 c/s to 20 000 c/s, it is possible to carry out measurements over in a much wider frequency range, when corrections are made according to fig. 10.

Fig. 11 shows the frequency response of the Level Recorder Type 2304, and it is clearly seen that this instrument will be the one which determines the low frequency cut-off of the measuring arrangement shown in fig. 1. In all the frequency characteristics shown the sensitivities are plotted as relative sensitivities and given in db.

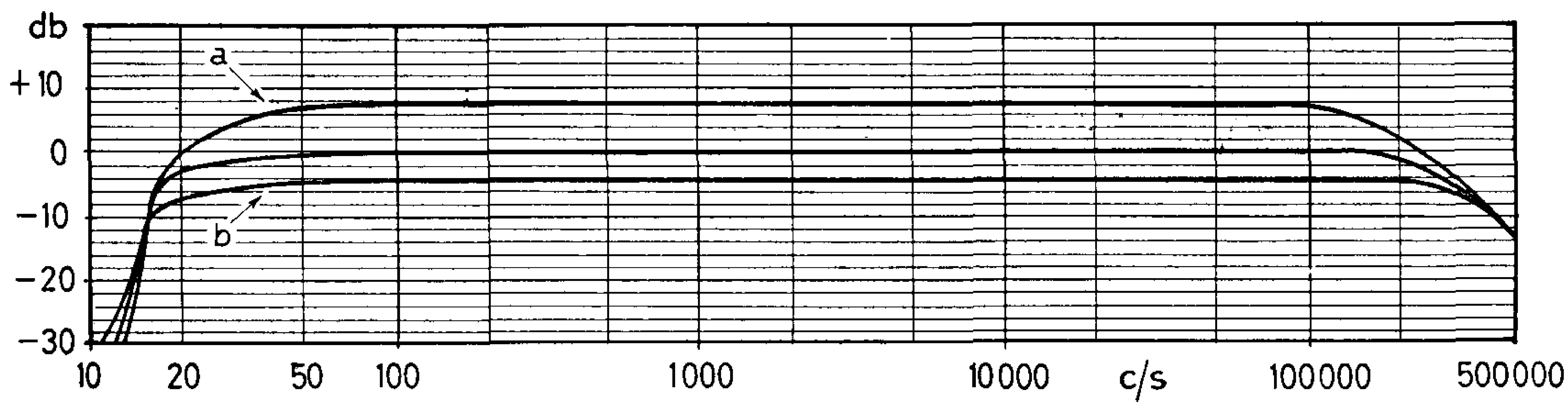


Fig. 11. Frequency response of the Level Recorder Type 2304. The frequency characteristic of the instrument is somewhat dependent upon the position of the knob marked "Sensitivity Adjustment" Curve a) is valid for the knob in position maximum, and curve b) for the knob in position minimum sensitivity.

To obtain the curve shown in fig. 2 it is then only necessary to subtract the curves of figs. 4, 6, 9 and 10 from each other.
However, when *exact* measurements are to be carried out it is recommended to measure the frequency characteristic of the total measuring set-up as used in the actual measurements. This is readily made by applying a signal of approx. 50 mV to the input of the preamplifier via a capacitor of approx. 700 pF and measure the deflection on the indicating instrument, see fig. 12.

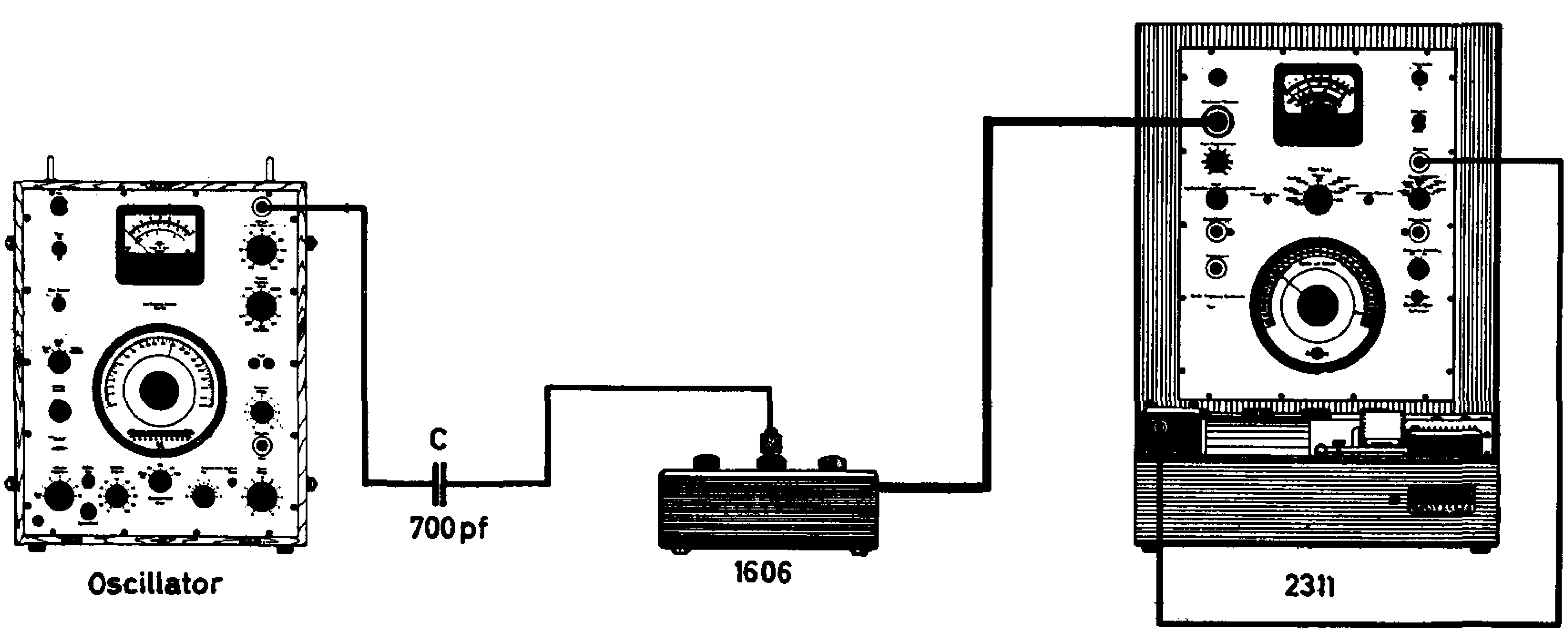


Fig. 12. Measuring set-up for the determination of the frequency characteristic of the complete vibration measuring system consisting of Accelerometer Type 4309, Preamplifier Type 1606, Spectrum Recorder Type 2311 and including the measuring cables.

By varying the frequency of the input signal and keeping the amplitude of the signal (Vo) constant, the frequency characteristic can be plotted from the meter readings.

The upper limit of the flat frequency response is normally determined by the mechanical resonance of the accelerometer. However, when the electronic measuring device shows a falling frequency characteristic at frequencies where the response of the accelerometer is raising, a compensation takes place, and the flat response of the total set-up is somewhat extended.

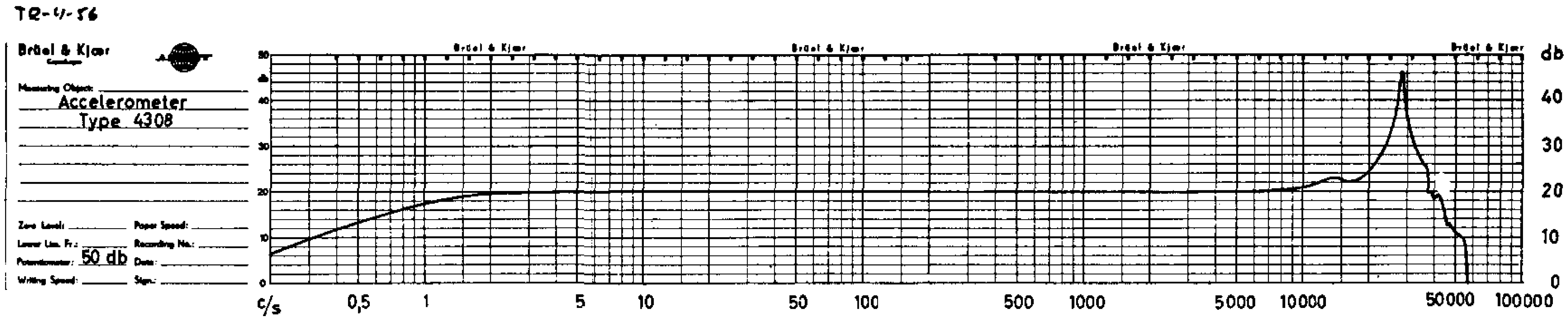


Fig. 13. Frequency characteristic of the Accelerometer Type 4308.

The flat response of the Accelerometer Type 4308 can be extended to a certain degree, when use is made of this effect. Fig. 13 shows a typical frequency characteristic of 4308 and when the suitable position of the sensitivity control in the Preamplifier Type 1606 is chosen the total response will be as indicated in fig. 14.

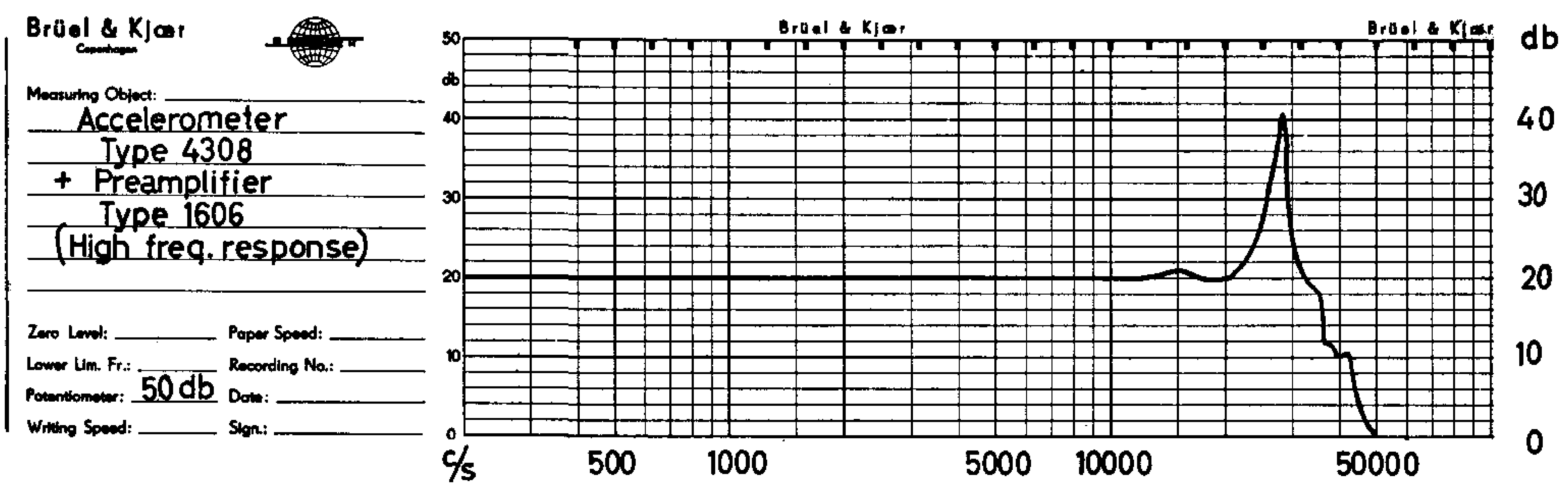


Fig. 14. High frequency characteristic of the Accelerometer Type 4308 + Preamplifier Type 1606. The Preamplifier is adjusted to extend the flat frequency response of the Accelerometer upwards.

So far only acceleration measurements of pure sinusoidal vibrations has been considered.

Most of the vibrations to be measured in practice are non-sinusoidal and to be able to obtain reliable measuring results of these types of signals care must be shown as to what the deflection on the indicating meter actually means.

A discussion on this subject with regard to noise measurements was given in T. R. no. 1-1956, and only the main points which are of interest when vibration measurements are taken, will be summarized below.

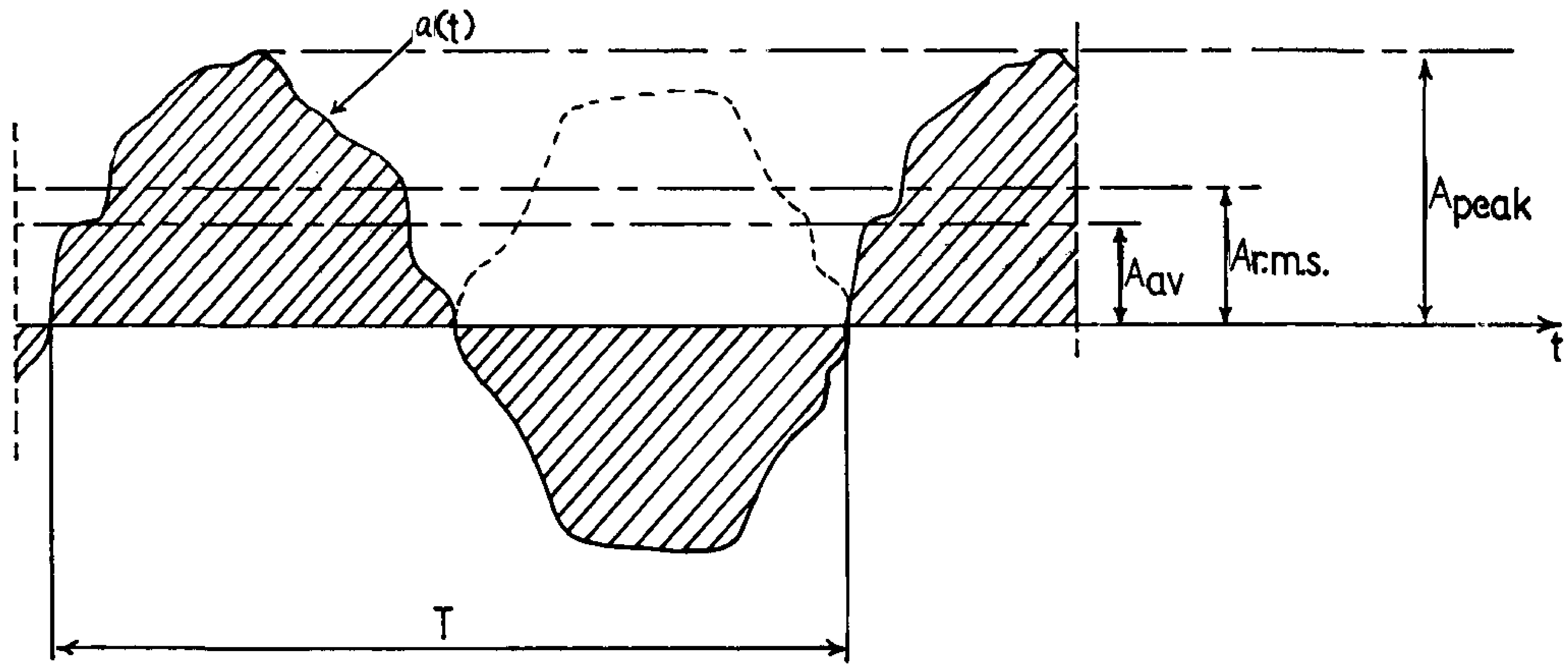


Fig. 15. Example of a periodic signal with indication of the peak, r. m. s. and average value.

An example of a periodic non-sinusoidal signal is shown in fig. 15, and the magnitude of such a signal may be expressed in different ways. One method of expressing the magnitude is by means of the *average value* of the signal normally defined by

$$A_{av} = \frac{1}{T} \int_0^T |a\ (t)|\ dt$$

Where T is the time interval between two successive moments of equal phase, see fig. 10.

A further method is to state the *root mean square* (or effective) value of the signal defined by:

$$A_{r.m.s.} = \sqrt{\frac{1}{T} \int_0^T [a\ (t)]^2\ dt}$$

Finally it is often wanted to know the maximum value that the signal may reach within a period, and this value is known as the *peak value* of the signal.

In fig. 15 is indicated the significiance of the above definitions with regard to a periodic signal of period T.

It is possible to give an indicating instrument a characteristic which makes the meter deflection proportional to any of the three definitions given, and when measurements on complex signals are carried out care should be taken as to which type of indicating instrument is used.

The Audio Frequency Spectrometer Type 2109, Microphone Amplifier Type 2602, Frequency Analyzer Type 2105 and the A. F.-Voltmeters produced by Brüel & Kjær measure the average value of the input signal.
However, all these instruments are calibrated in the r. m. s.-value of a sinusoidal signal. This is practical as in most cases it is desired to know the r. m. s.-value of the measured signal, and when the wave-shape of the signal is known only a mathematical transformation is necessary to express its magnitude by means of the different definitions. Each type of signal will, however, require a new transformation formula, and when a non sinusoidal signal is measured the measurements are normally carried out as a frequency analysis of the signal considered. This method of measurement is based upon the theory given by Fourier and stating that any periodic, complex signal can be expressed as a series of pure sinusoidal signals, the series being:

$$a = A_0 + A_1 \cdot \sin(\omega t) + A_2 \cdot \sin(2\omega t + \varphi_1) + A_3 \cdot \sin(3\omega t + \varphi_2) + \ldots\ldots A_n \cdot \sin(n \cdot \omega t + \varphi_{(n-1)})$$

where A is the magnitude of the different sinusoidal signals, and $\omega = 2\pi f$ (f = fundamental frequency of the signal considered).
φ is the phase angle of the individual higher order sine waves relative to the fundamental.
When this series is known the complex signal is also known. In most practical cases it will only be necessary to know the magnitude A of the individual sine waves, irrespective of their relative phase angles, and by means of a frequency analyzer the constant A_1, A_2, A_3 .... A_n can be determined.

At extremely low frequencies (< 10 c/s) it is not practical to analyze the signal electrically due to the difficulties in designing a reliable analyzing equipment for use in this frequency range. A mathematical method of analysis should then be employed.

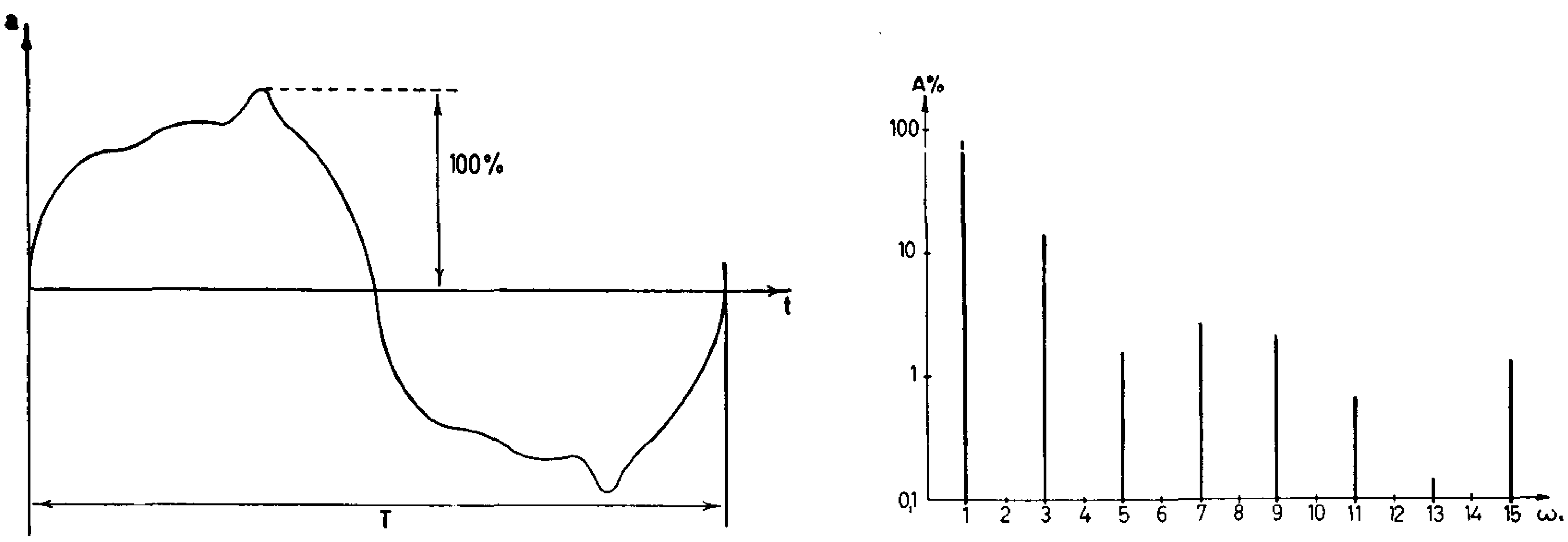


Fig. 16. Example of a complex signal, and its frequency spectrum ($\omega_0 = \frac{2\pi}{T}$).

The signal to be analyzed can be displayed on the screen of an oscilloscope and photographed, or it can be recorded on an oscillograph, whereafter the complex wave can be analyzed by means of known mathematical methods. A complex signal together with its frequency spectrum (the constants A of the Fourier-series) is shown in fig. 16. When a considerable number of harmonics are to be measured the octave selectivity of the analyzing equipment must be rather high. However, for normal requirements the selectivity of the Audio Frequency Spectrometer Type 2109 and Frequency Analyzer Type 2105 is sufficient.

When a complex signal consisting of a fundamental frequency and its harmonics is analyzed, by means of the instruments Type 2109 or Type 2105 the individual measurements consist of measuring a sinusoidal signal, and the value read on the instrument meter is the r. m. s. value of a sine-wave.
If the total signal is measured on a non selective vacuum tube voltmeter e. g. Microphone Amplifier Type 2602 the *deflection* of the instrument meter will be proportional to the average value of the signal. The meter-*reading* however, will be 1, 11 times greater than the actual average value of the input signal.
To obtain the r. m. s. value of the complex signal from measurements on an average reading, non selective measuring instrument, is not possible, and it is therefore recommended to use this type of measuring equipment only for relative measurements.

When measurements are taken on vibrating machinery it might sometimes be of considerable interest to obtain an idea of the peak value of the vibrations. None of the instruments mentioned above are able to indicate peak values. However, by applying the total signal to a calibrated oscilloscope or a peak-reading voltmeter the necessary information can be obtained.
If an oscilloscope is used the indication on the screen is the peak — to — peak value of the signal, and some difficulties may arise when the measured result is to be evaluated.
If, on the other hand, a peak-reading voltmeter is employed, it is normally possible to measure the positive and negative peak-value separately.

Turning back to the measuring arrangement of fig. 1 some remarks should be made on the Audio Frequency Spectrum Type 2311. As mentioned previously this instrument contains both the Spectrometer Type 2109 and the Level Recorder Type 2304. The meter indication on 2109 is, as stated above, proportional to the average value of the input signal. However, the deflection on the Level Recorder Type 2304 is proportional to the peak value of the signal, the instrument containing a half-wave peak rectifying circuit.
This is of importance when complex signals are measured directly, i. e when the Spectrometer is switched to "Lin.".

If both the Spectrometer and the Level Recorder have been calibrated with a sinusoidal signal, and a complex voltage is measured the meter-reading on the Spectrometer and the indication on the Level Recordder will not be identical, which at first sight might cause confusion. Remembering the difference in the rectifying circuit the difference in indication is readily understood, and *the measured results contain information both on the peak-value and on the average value of the signal considered.*
However, when the Spectrum Recorder is used for measurement of the total signal, i. e. when switched to "Lin.", an error is introduced if the vibration spectrum contains large high frequency components.
These components will then exite the mechanical resonance of the accelerometer and the instrument will indicate a too high value, due to the increased sensitivity of the Accelerometer at frequencies around the resonance point. It is therefore advisable always to analyze the vibrations which are being measured.

An advantage gained by employing the Spectrum Recorder as indicating instrument compared with other frequency analysing arrangements is that the analyses of vibrations can be carried out automatically because of the mechanical coupling between the filter switch in the Spectrometer and the motor drive in the Level Recorder. If desired this coupling can be released by means of a switch, and "manual" measurements be taken.
An example of an automatically recorded Spectrogram of a motor's vibrations is shown in fig. 17.

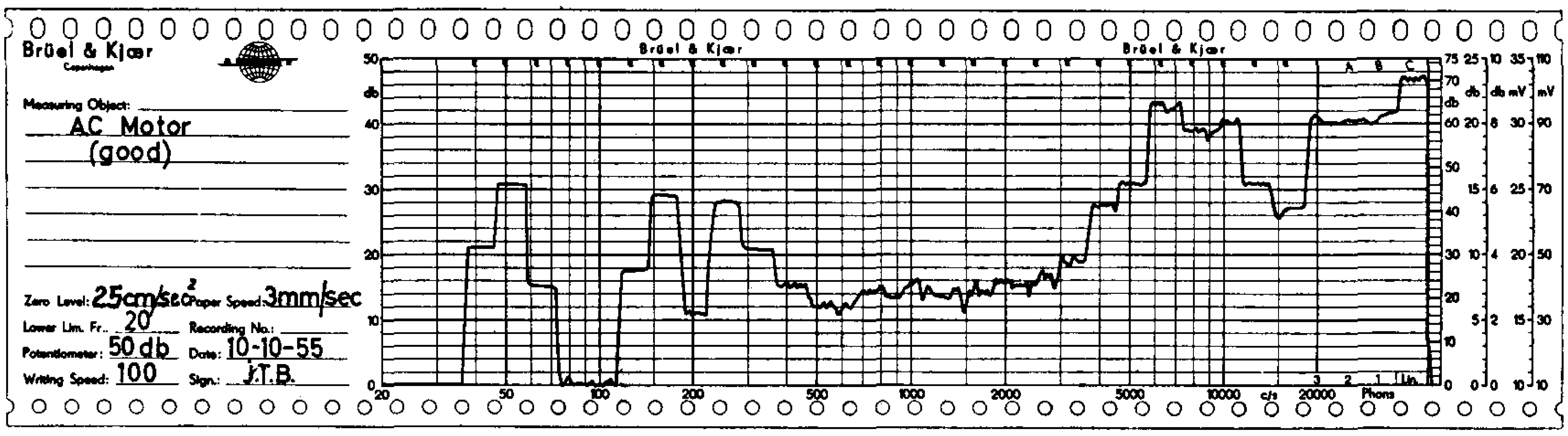


Fig. 17. Recording of the vibrations in a motor's base. The measuring arrangement of fig. 1 was used, and the Preamplifier was switched to measure acceleration. 0 db = 25 cm/sec².

Up to this point the discussion has been based on measurements of acceleration. This is, as stated previously, normally the most important mechanical quantity to measure when vibrations are concerned. However, sometimes it is of considerable interest also to measure the other, related quantities, namely the velocity and the displacement.

When pure sinusoidal vibrations are considered the velocity and the displacement can be found mathematically from the measurement of acceleration as:

Velocity $$v = \int_0^t a\,dt = A \int_0^t \sin(\omega t)\,dt = -\frac{A}{\omega}\cos(\omega t)$$

and

Displacement: $$s = \int_0^t\int_0^t a\,dt\,dt = \int_0^t v\,dt = -\frac{A}{\omega}\int_0^t \cos(\omega t)\,dt = -\frac{A}{\omega^2}\cdot\sin(\omega t)$$

The velocity and the displacement of complex signals cannot be found mathematically from the measurement of acceleration. In these cases the Preamplifier should be switched to position "Velocity" or "Displacement" respectively.

A discussion on the use of the different characteristics for the integration networks is carried out in T. R. no. 2 — 1955, and will not be dealt with. It should only be mentioned that the highest sensitivity of the measuring arrangement is obtained when the switch on the Preamplifier is set to the highest "Lower Limiting Frequency" permissable for the measurements in question.

Before closing the discussion some remarks should be made regarding the calibration of the Accelerometers Type 4308 and 4309. The sensitivity indicated on the individual calibration curve supplied with the Accelerometer when it is delivered to the customer is checked at the factory by means of a vibrator at a frequency of 50 c/s. The acceleration used for the production check is 1 g* = 981 cm sec^{-2}, and the sensitivity is given in mV/g*, where both the electrical and the mechanical quantity are the peak values of a sinusoidal signal. The sensitivity given includes the attenuating effect of the low-noise cable supplied with the instrument when delivered from the factory.

The frequency characteristic of the Accelerometers are measured by means of a specially developed electro-dynamic vibrator. This vibrator is designed to act as a rigid, vibrating mass up to frequencies of approx. 60—70 kc/s thereby simulating large vibrating machinery parts, and making the influence of the accelerometer upon the exiter negligible.

Before actual measurements on vibrations are carried out the different problems involved in the measurements should be considered, and it has been the intention of this article to indicate the problems present when a measuring arrangement of the type shown in fig. 1 is employed.

The discussion on the vibration pick-up itself has been based on the use of piezo-electric accelerometers of the Type 4308 or 4309. Other types of pick-ups may of course also be used, but the problems regarding the connecting cables and the use of the Preamplifier Type 1606 must then be seen in view of the change in mechanical-electrical transducer.

Some Typical Applications of Vibration Measuring Technique in Modern Industry.

By Jens T. Broch M. Sc.

The Accelerometers Type 4308 and 4309 are the result of years of development and experience and the frequency characteristics of the transducers are technically remarkable, when the relatively high sensitivity, the great temperature range and permissable humidity are taken into account.
In the design of modern Accelerometers not only the mechanical-electrical properties of the instrument plays an important rôle, but also the physical size and weight must be considered.

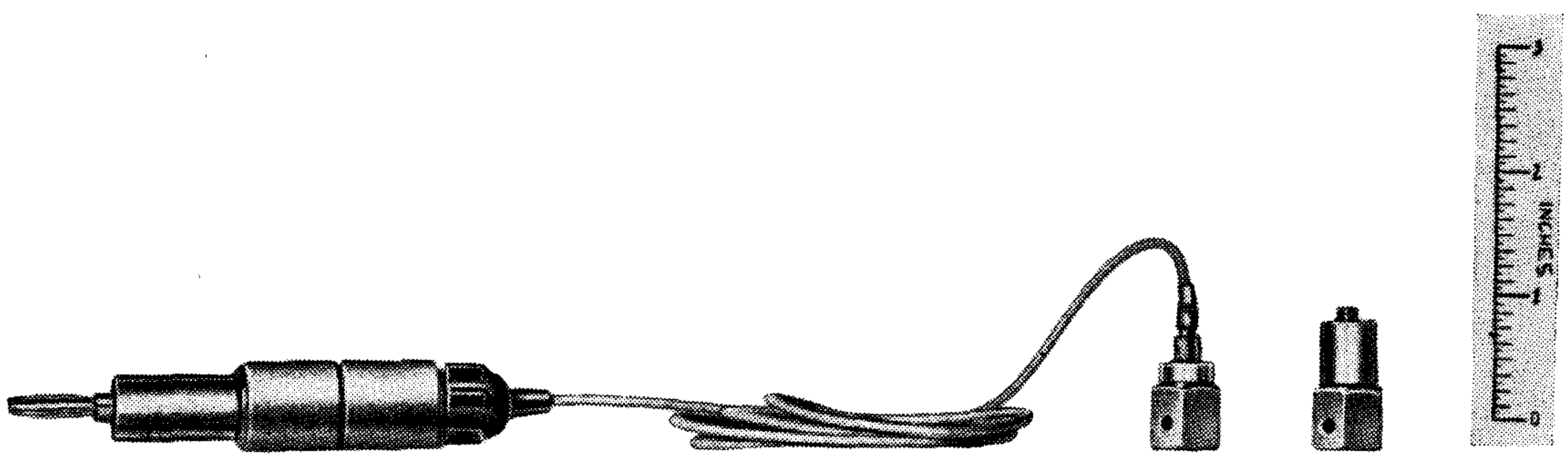


Fig. 1. Photo of the Accelerometers Type 4308 and 4309.

In the preceeding article the problems arising when exact vibration measurements are required have been discussed.
It might, however, be of interest to see how vibration measurements can be applied to modern industrial problems, and some typical examples of this type of application will be given in the following. In the examples shown the Accelerometer Type 4308 or 4309 were used as vibration pick-up, and a photo of the Accelerometers is shown in fig. 1.

To be able to mount the Accelerometer in different ways in situations where space is limited the instrument must have small physical dimensions, and to avoid reaction from the accelerometer upon the object under test when the test-object itself is small and light the weight must be the smallest possible. Also these requirements are fulfilled by the Accelerometers Type 4308 and 4309, as can be seen from the technical specification given below.

Accelerometer Type	**4308**	**4309**
Sensitivity in mV/g[1])	approx. 20	approx. 6
Weight in grs.	25	18
Resonance frequency in kc/s	25—35	40—50
Capacity in pF	700	700
Frequency range in c/s	5—20000	5—30000
Max. permissable acceleration in multiples of g[1])	1000	2000
Smallest leakage resistance in ohms	2×10^8	2×10^8
Smallest acceleration to be measured with Preamplifier 1606 and 2109 (or 2105) cm/sec^2	0,25	1
Max permissable ambient temperature ° C	100	100
Permissable humidity %	0—100	0—100

[1]) g = 981 cm/sec^2

Mechanical Dimensions:

Height in mm	30	20

Both Types of Accelerometers have the same hexagonal base which is 14 mm across the flats.

Typical sensitivity data when used in connection with Preamplifier 1606.

Accelerometer Type:	**4308**	**4309**	**Position of Switch lower limiting frequency**
Acceleration cm/sec^2	0,25	1	
Velocity cm/sec	0,0025	0,01	3
	0,0013	0,005	30
Displacement μ[2])	0,13	0,5	3
	0,025	0,1	30
	0,005	0,02	300

[2]) 1 μ = 40 μ inches (40×10^{-6} inches).

There are four types of vibration measurements which may be considered as most important.

1. Vibration measurements in development.
2. Vibration measurements in connection with the installation of large machinery to enable the best possible vibration insulation.
3. Vibration measurements which enable faults in rotating machinery to be detected.
4. Vibration measurements used for checking the performance of rotating machinery (production control).

Measurements of the types mentioned under item 1 to 3 should be carried out as selective measurements, i. e. the vibration spectrum should be analyzed by means of a frequency analyzer.
Production control of rotating machinery, however, may be carried out as non-selective measurements, and will in most cases be less critical than the other types listed above.

An old adage says that "prevention is better than cure", and it is obvious that if mechanical structures are developed in such a way that the vibrations produced by the final products are negligible, this will be a better solution to the vibration-problem than any "external" vibration insulation technique which can be applied. The field of vibration measurements in development is therefore large, and each individual problem must normally be considered separately.

On the other hand, the type of vibration measurements mentioned under item 2 may be considered as a "standard" measurement, and a typical measuring arrangement for the determination of the quality of vibration insulation applied to a rotating motor installed in a factory is shown in fig. 2 a. The arrangement consists of the Accelerometer Type 4308, the Preamplifier Type 1606 and the Frequency Analyzer Type 2105.

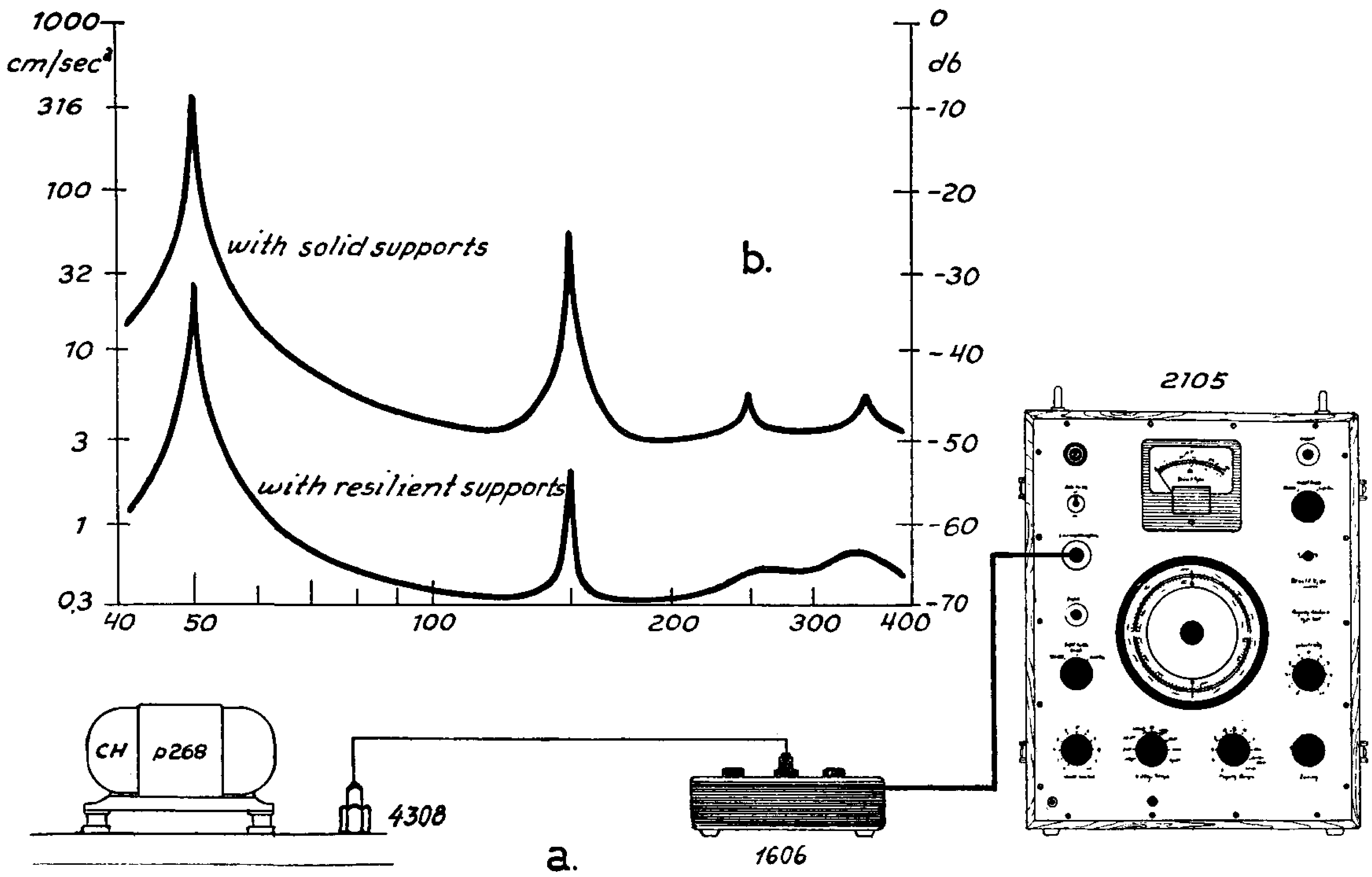


Fig. 2. Vibration measurements in connection with the installation of an a. c.-motor.
a) Measuring arrangement.
b) Measured results.

The Frequency Analyzer Type 2105 which employs a degenerative feed back system can not be used in conjunction with the Level Recorder Type 2304 for automatic analysis of a frequency spectrum.

The frequency spectrum considered must be measured "manually" and the curves plotted according to the meter readings, fig. 2 b.

Fig. 2 b shows the analysis of the vibrations in the floor, first when the motor was set up on solid supports, then when it was suspended on vibration absorbers. The measurements were taken as acceleration measurements. Powerful vibrations can be seen to occur at 50 c/s and 150 c/s. However, the application of resilient supports reduces the external effect of the vibrations by approx. 20 db.

To judge the effect of vibrations on the human organism a set of curves as plotted in fig. 3 may be used. In the figure the relationship between the

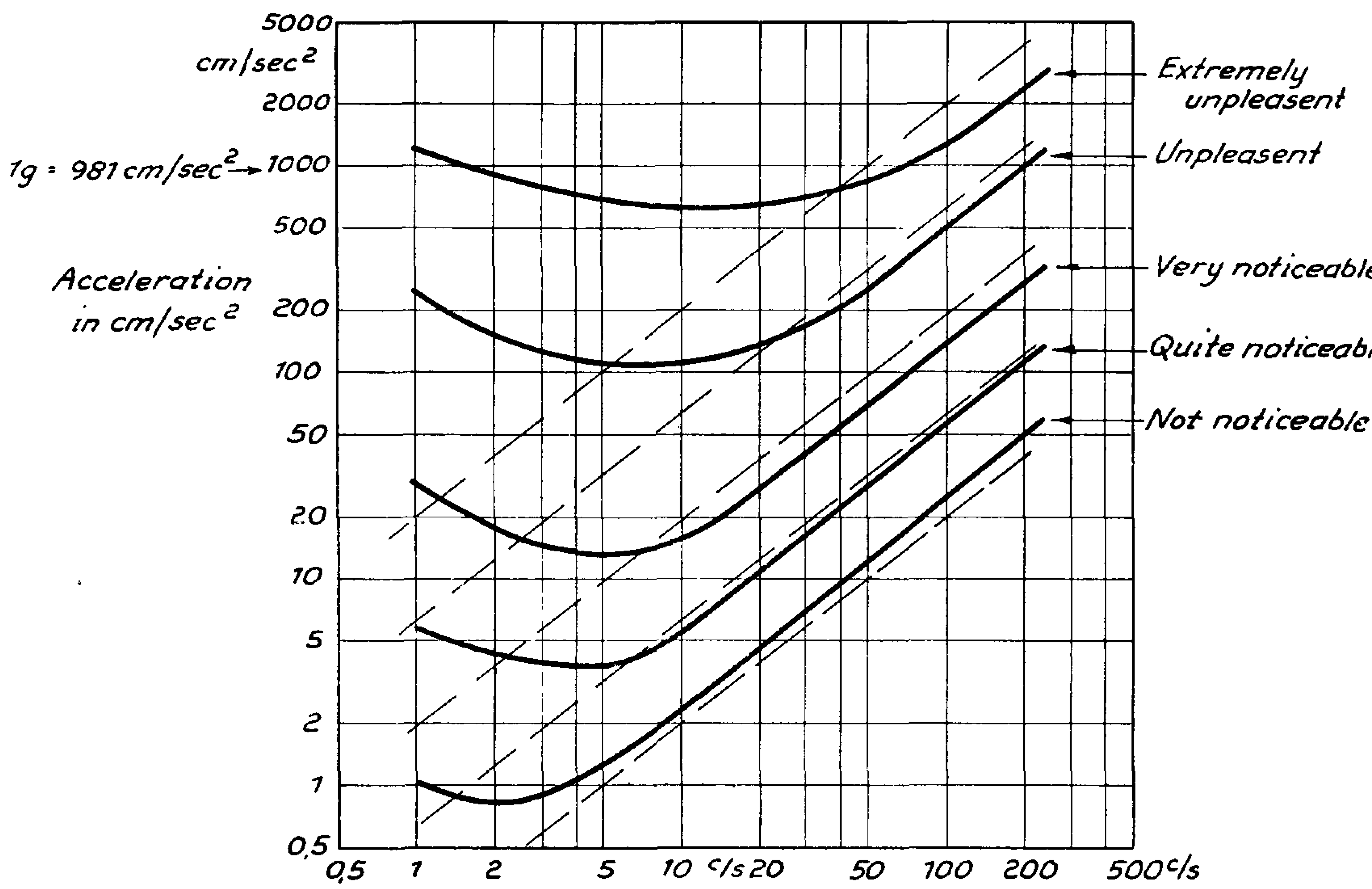


Fig. 3. Chart for the determination of the "irritation effects" of vibrations on the human organism.

acceleration, the frequency of the vibrations and the degree to which they are noticed by the human organism is shown. The curves are an average of results obtained from measurements on both sitting and standing persons, in which only sinusoidal vibrations were used.

It will be noted that at low frequencies the human judgment of the strength of vibrations is mainly dependent on and proportional to their velocity.

As can be seen from fig. 3, however, the relationship between the velocity of the vibrations and the human power of perception is not fulfilled for frequencies lower than 20—50 c/s. In practice it is therefore correct to use the continuous black curves.

When this set of curves is applied to the measured results indicated in fig. 2 it is found that the installation of vibration absorbers has reduced the vibrations from being very "Unpleasant" to "Quite Noticeable".

Another type of "standard" measurements is mentioned in item 3, and a suitable measuring arrangement is shown in fig. 4, consisting of the Accelerometer Type 4308, the Preamplifier Type 1606 and the Audio Frequency Spectrum Recorder Type 2311.

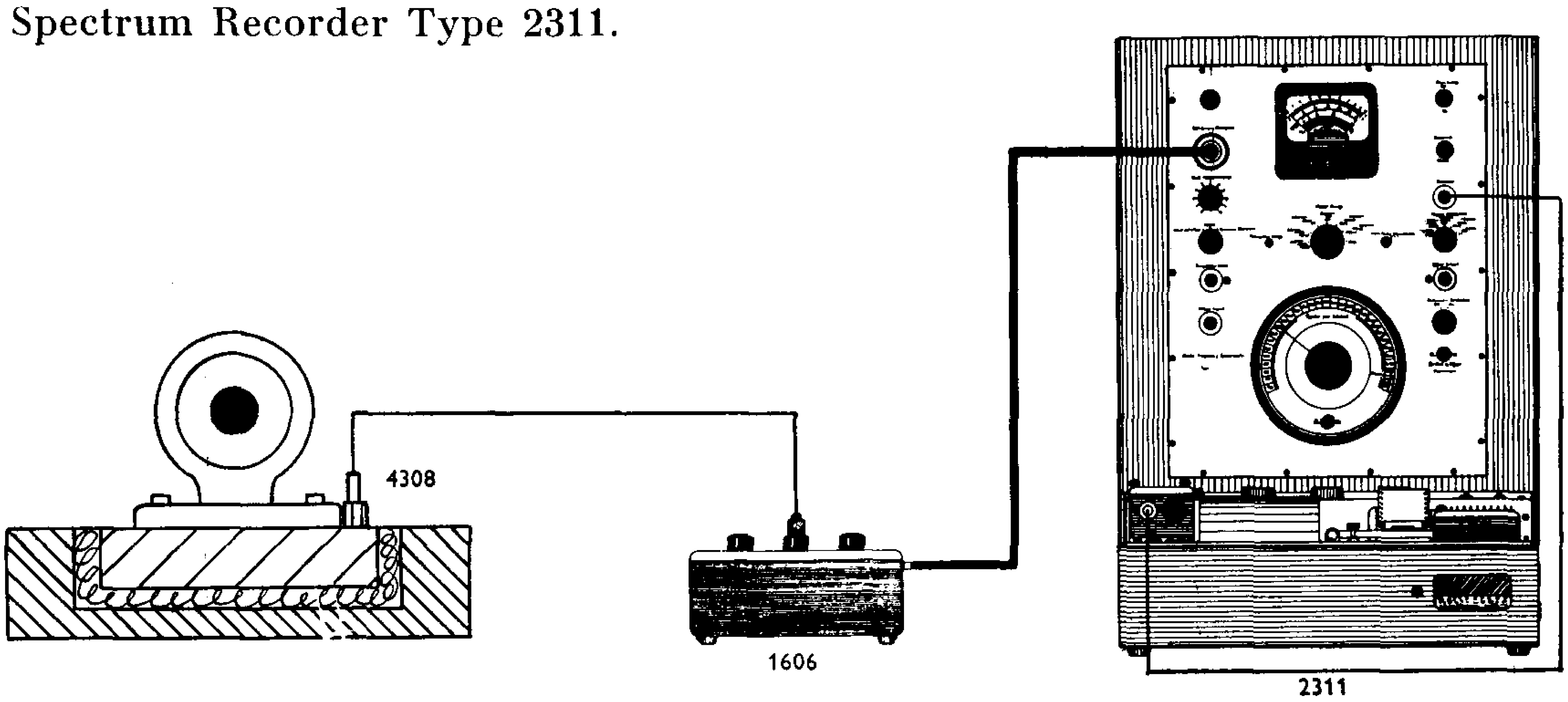
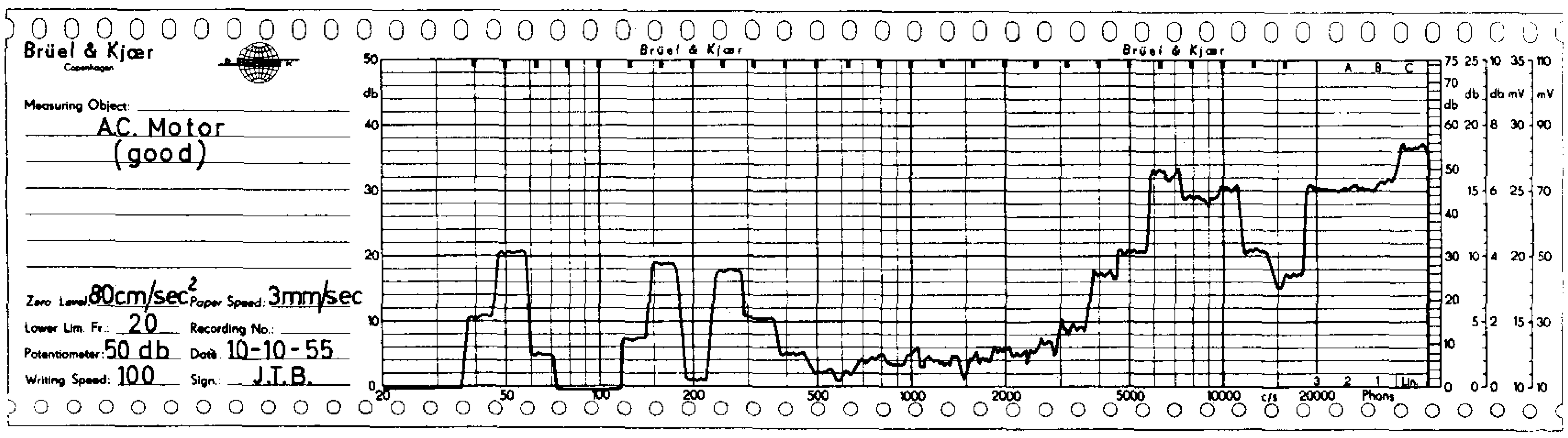
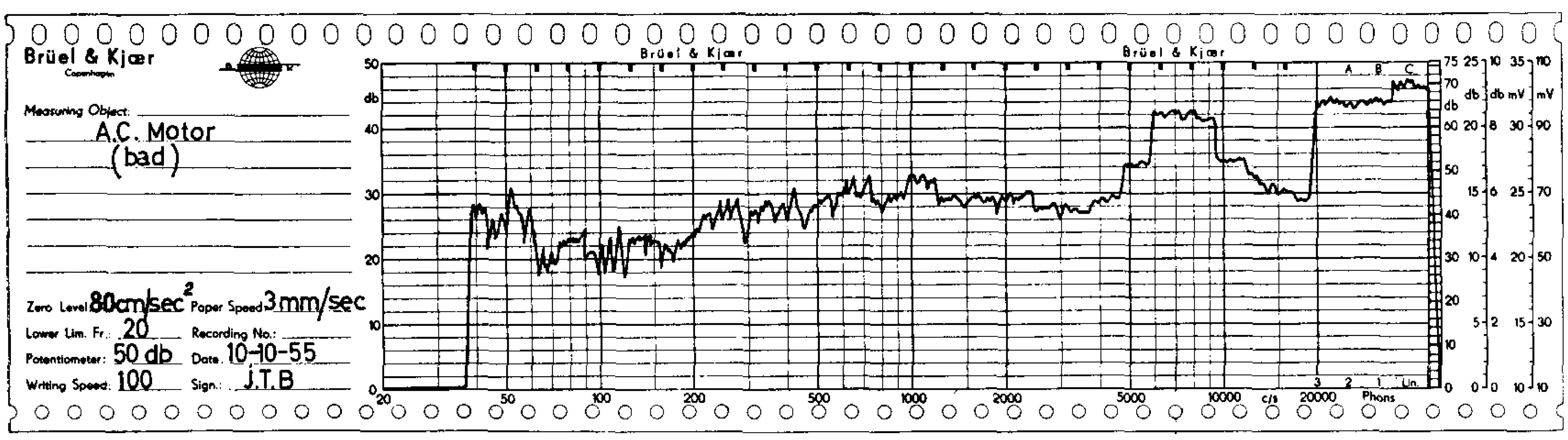


Fig. 4. Measuring arrangement for fault detection on rotating machinery.



5 *a.*



5 *b.*

Fig. 5. Spectrograms obtained with a measuring set-up as shown in fig. 4.

a) Spectrogram of the vibrations from a "normal" motor.

b) Spectrogram of the vibrations from a »faulty" motor of the same type.

This arrangement can be used to detect faulty motors and is a reliable and quick method of checking the mechanical performance of rotating machinery. An example of fault-detection is shown in fig. 5 a and b where the curve shown in fig. 5 a is the spectrogram obtained from measurements on a "good" motor, and fig. 5 b shows the spectrogram obtained from measurements on a motor of the same type but with a faulty bearing. The difference between the two spectrograms is clearly noticed.

Under item 4 was mentioned that vibration measurements may be used in production control of vibrating machinery, and it was also stated that in this case the measurements need not be carried out as selective measurements. The measurements are normally taken as relative measurements, and the absolute value of the vibrations is then of minor importance, as long as a certain predetermined limit is not exceeded.

This limit can be marked on the instrument meter scale, and the tester will then only have to reject machinery which shows vibration values above the mark.

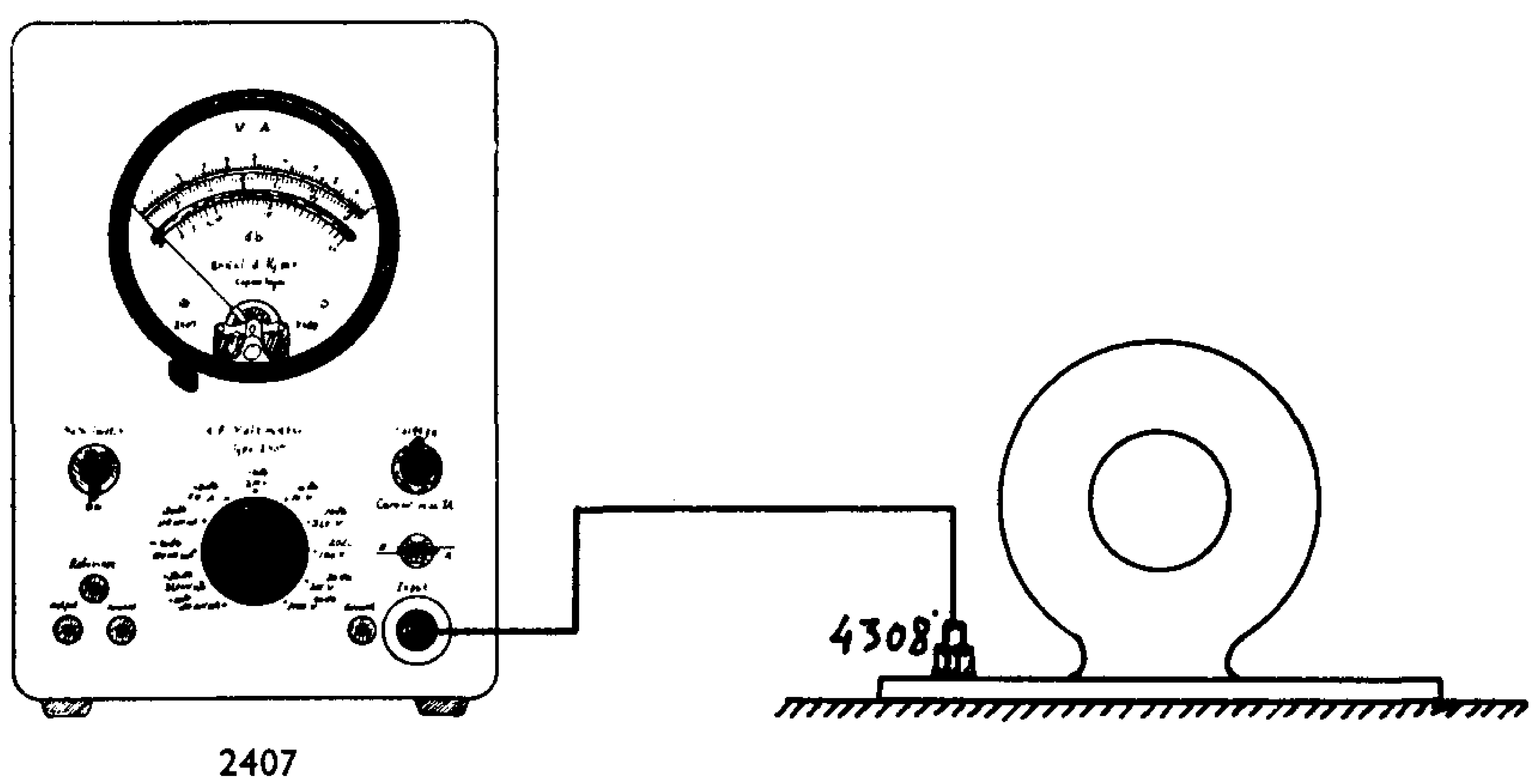


Fig. 6. Measuring arrangement suitable for quick production line checks on vibrating machinery.

A measuring arrangement suitable for production control is shown in fig. 6, and as indicated on the figure the use of Preamplifier Type 1606 will in most cases not be necessary.

It is then possible to employ the Audio Frequency Voltmeter Type 2407 as indicating instrument which makes the set-up inexpensive and convenient for quick production-line checks, on high-speed motors.

A further application of the Accelerometers Type 4308 and 4309, which may be considered as rather important, is the use of the pick-ups to control vibration exciters.

An important design consideration for modern vibrators is to obtain maximum rigidity for all table loads. To fulfil this requirement the weight of the moving element of the exciter should be great when compared with the test object.

However, employing an accelerometer to control the movement of the table makes it possible to reduce this weight, whereby smaller and cheaper vibration exciters may be used for the test under consideration.
A typical arrangement suitable for this type of vibration "measurements" is shown in fig. 7.

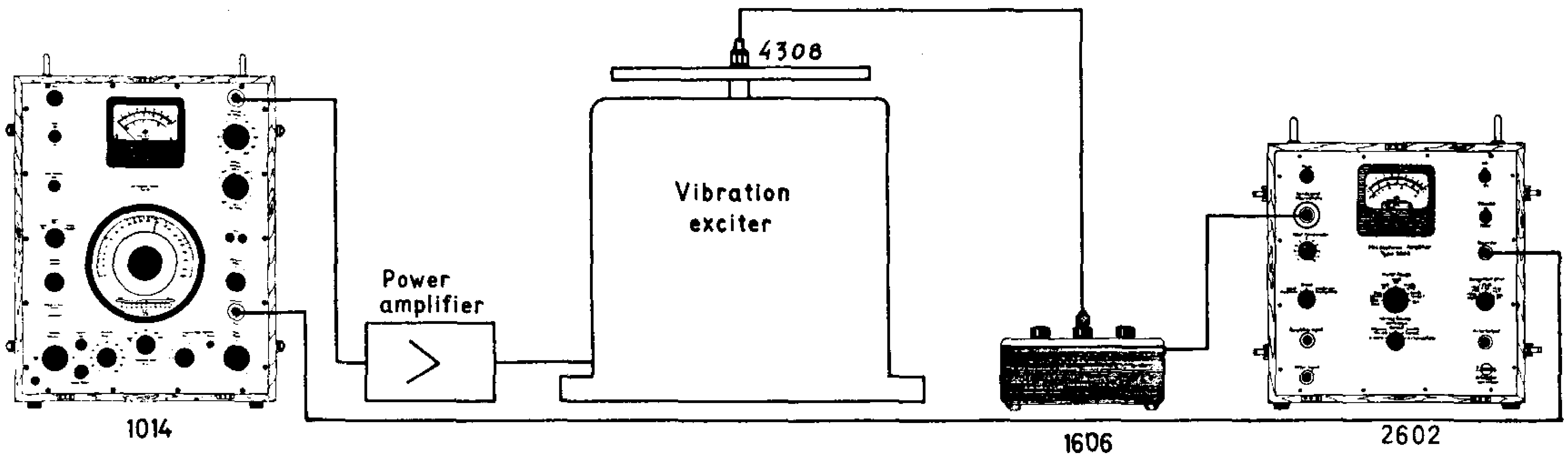


Fig. 7. Example of application of the Accelerometer Type 4308 for the control of vibration exciters.

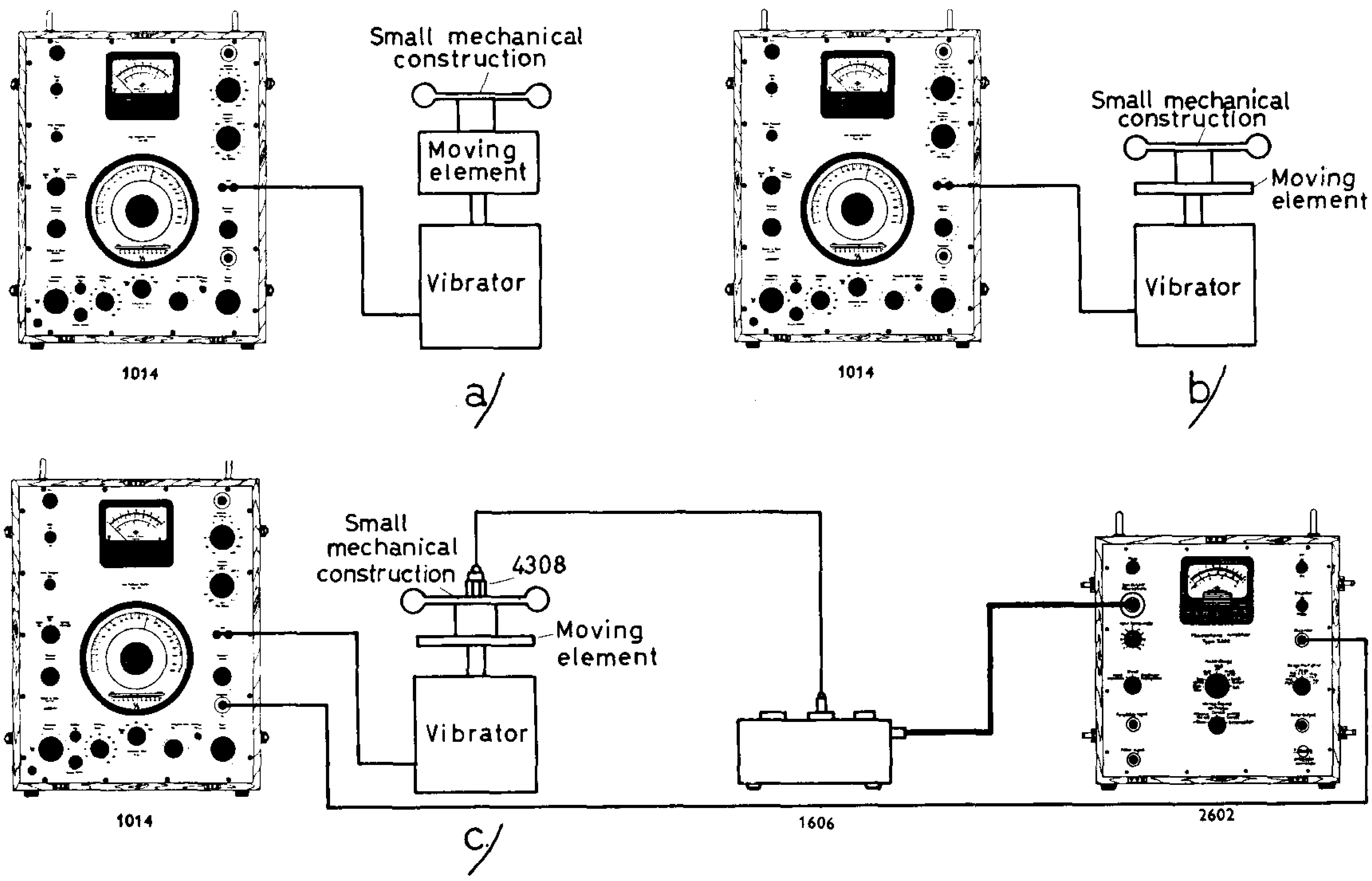


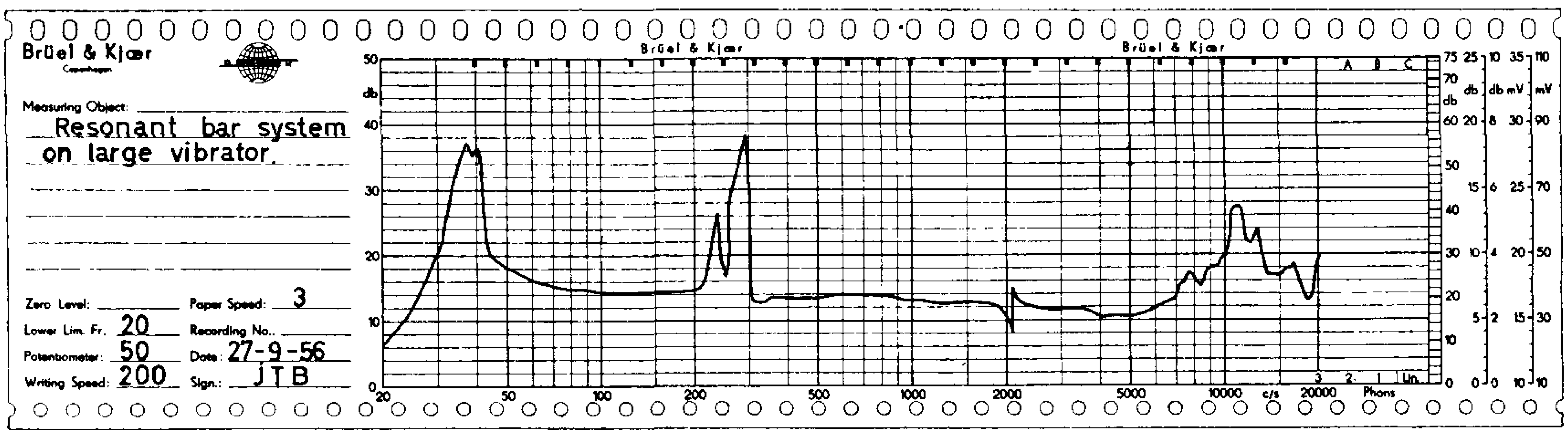
Fig. 8.

a) The structure being investigated is placed on a vibrator with a large moving mass, and the vibrator is driven from a Beat Frequency Oscillator Type 1014.

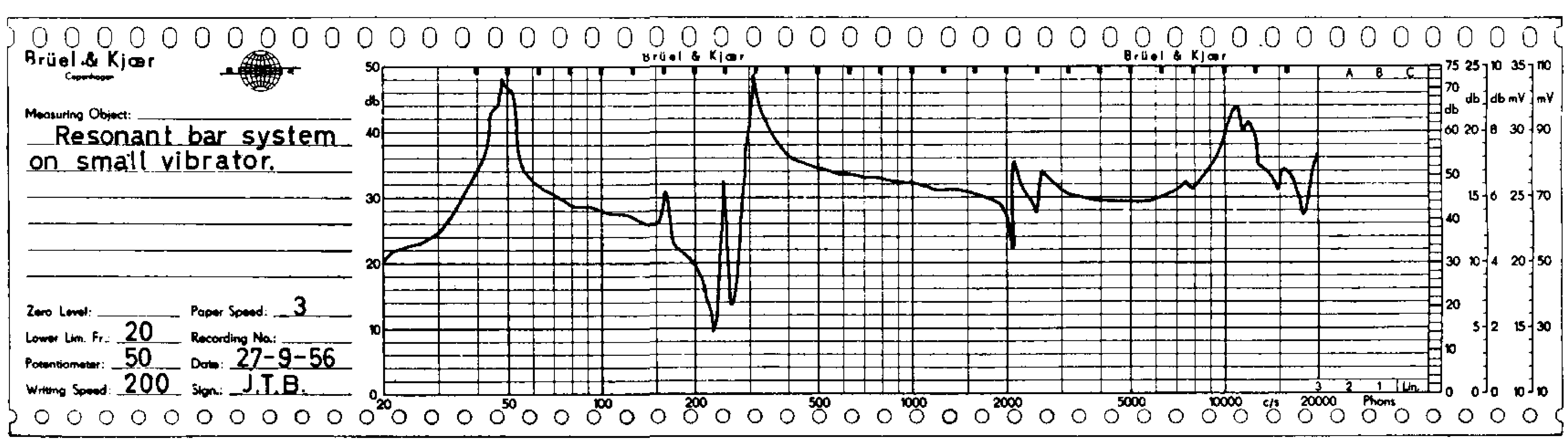
b) The same structure is placed on a vibrator with a moving element the mass of which is approx. 1/5th of that used in a).

c) The same structure is placed on the same vibrator as used in b). The movement of the vibrator, however, is now controlled by an Accelerometer Type 4308.

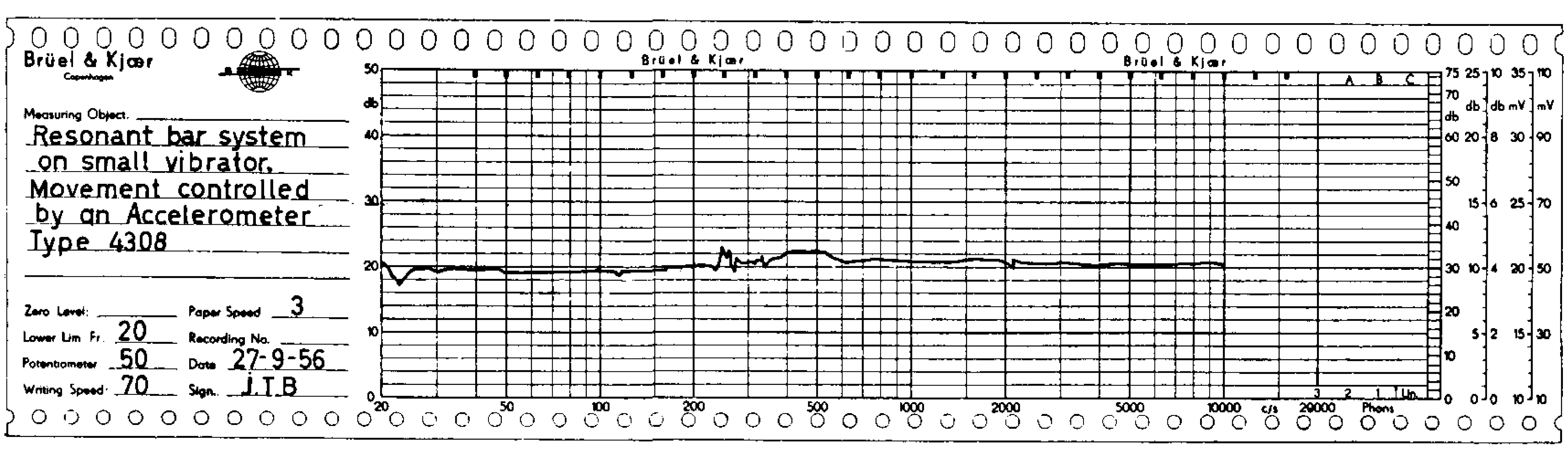
The vibrator is fed from an oscillator e. g. a Beat Frequency Oscillator Type 1014, via a power amplifier, and the output from the Acceleromter Type 4308 is amplified and fed to the "Compressor Input" of the B. F. O. Due to the automatic output regulation obtained in the B. F. O. when the compressor circuit is employed the acceleration of the vibrations, and thereby the vibrating force, is kept constant throughout the frequency range considered. The moving element of the vibrator thus acts as a large rigid mass, and its movement will not be influenced by different table loads, within the limits of the control arrangement, see fig. 8 and 9.



a)



b)



c)

Fig. 9. Curves showing the acceleration of the moving element of the vibrator shown in fig. 8 as a function of frequency.

Curve a): Acceleration of the vibrator shown in fig. 8a).
Curve b): Acceleration of the vibrator shown in fig. 8b).
Curve c): Acceleration of the vibrator shown in fig. 8c).

Employing the Microphone Amplifier Type 2602 the set-up can be calibrated and the magnitude of the acceleration read directly off the instrument meter. The examples of vibration measuring technique given here are only meant as a few illustrative examples of this important type of modern measurements, and there is of course several other fields of technical importance such as the vehicles-, ships-, and aircraft industry where vibration measurements are applied. The release of the two wide-range Accelerometers Type 4308 and 4309 therefore satisfies a long felt need for a high-frequency accelerometer which makes it possible to apply the B & K "automatic measuring technique" also in the field of vibration measurements.

News from the Factory:

Modification of Level Recorder.

Type 2304 and Type 2334

The motor in the Level Recorder, which up to now has been an asynchronous motor has been replaced by a new *synchronous* motor.

This new motor has a considerably higher starting torque than the "old" motor, which in many applications is a great advantage.

All Level Recorders subsequent to serial number 17335 are supplied with synchronous motors.

The motor speed adjustment which until now has been carried out by means of a stroboscopic disc illuminated by a neon tube will therefore no longer be necessary, the new motor running at a constant speed determined by the frequency of the mains.

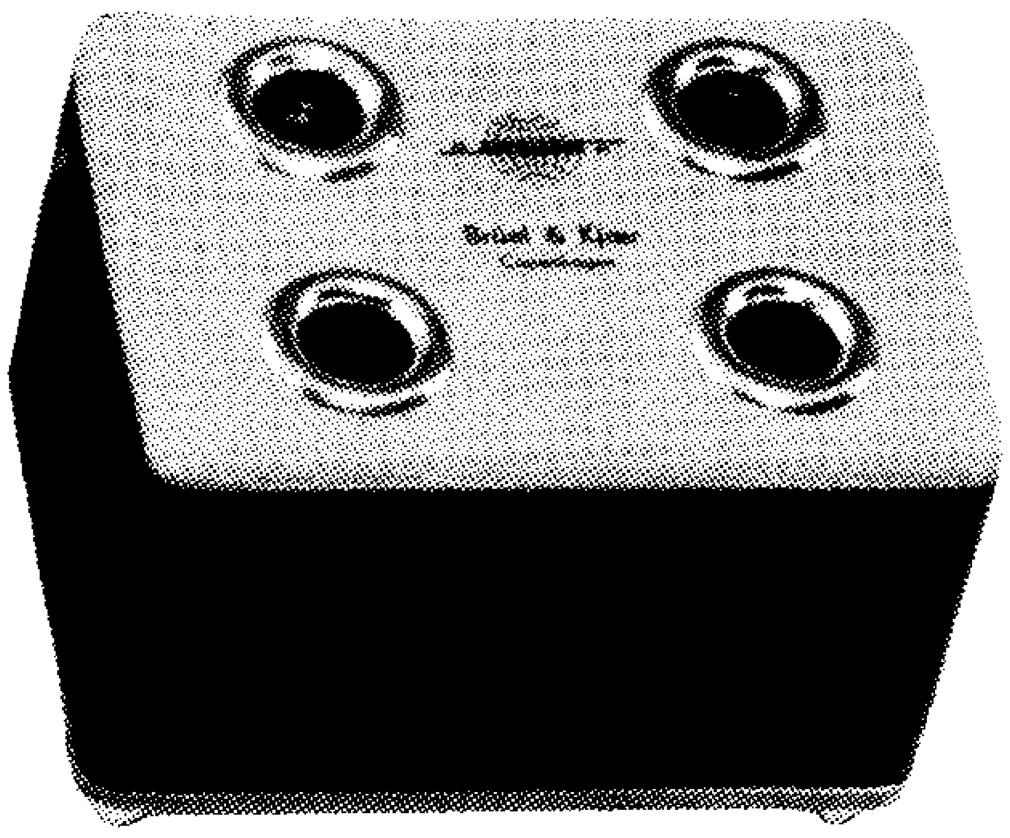
The adjustment of the Level Recorder, with exception of the motor speed adjustment, is not influenced by this modification. However, due to the rating of the new motor, *all Level Recorders for 50 c/s operation are connected for 220 volts, unless otherwise specified by the customers in their order,* and no voltage selector is provided.

When rotary converters are used to feed the Level Recorder from a d. c. power line the frequency generated on the a. c. side of the converter must be exactly the one specified for the Level Recorder if a correct motor speed as stated in the Level Recorder specification should be obtained.

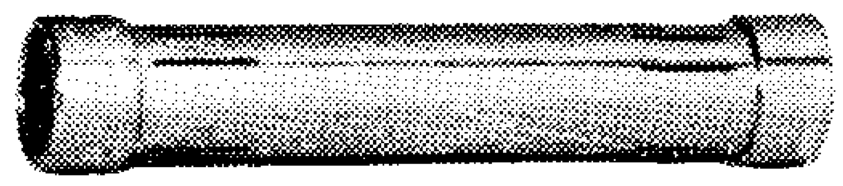
Connection Cables Type AO 0019 and AO 0020.

Similar to the Connection Cable Type AO 0014. Lengths 3 m and 10 m, respectively.

Screened Connection Box Type JJ 0004.
This Box enables easy parallel connection of four cables AO 0014, and a photo of the Box is shown below (1/3rd of actual size).



Type JJ 0004



Type JJ 0005

Extension Connector Type JJ 0005
made to facilitate the connection between two cables AO 0014. The Connector JJ 0005, together with the Connection Cables Type AO 0014, AO 0019 and AO 0020, makes the Screened Socket Type JJ 0015 and the Extension Cables Type AO 0015 and AO 0016 superfluous and the production of these items is therefore stopped. A photo of the new Connector is shown above (1/3rd of actual size).

Type No. 4348 and 4349.
Due to the increase in production capacity it has been found possible to meet the demand for a Low-Price Accelerometer Unit.
The Accelerometer Sets Type 4308 and 4309 are delivered in a case, and consists of:

- 1 Accelerometer 4328 (or 4329)
- 1 Probe 10 cm long
- 1 Probe 3 cm long
- 1 connecting cable 1,2 m long, with plugs.
- 10 screws for mounting of the Accelerometer
- 1 screwdriver (Allen key)
- 1 screw-tap (1/8″ Whitworth).

However, when the Accelerometers are required in quantity they can be delivered without accessories in a simple packing at reduced price.
This package will then contain five Accelerometers and five connecting cables 1,2 m long. Attached to the end of the connecting cable is a plug to fit the socket on the Accelerometer. The other end of the cable is left without connection.
Type 4348 then consists of 5 Accelerometers, i. e. Type 4328 and connecting cables Type AO 0022, and
Type 4349 consists of 5 Accelerometers, i. e. Type 4329 and connecting cables Type AO 0022.

Brüel & Kjær

ADR.: BRÜEL & KJÆR
NÆRUM - DENMARK

TELEPHONE: 80 05 00
BRUKJA, Copenhagen

Printed in Copenhagen, Denmark