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Stereophonic Gliding Frequency Record

No. 3 1962

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TECHNICAL REVIEW

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K. LARSEN & SØN - LYNGBY

Testing of Stereophonic Pick-ups by means of Gliding Frequency Records

by

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ABSTRACT

After a survey of the principles of stereophonic disk reproduction, there follows a short analysis of the problem of production testing of stereophonic pick-ups, forming the technical background of the B & K Gliding Frequency Records. These new test records are critically described and the different associated measuring methods are discussed mainly with regard to the automaticity and rapidity of operation. Finally, some experimental results are shown.

SOMMAIRE

Après un rappel des principes de la reproduction stéréophonique sur disques, le problème des essais en série des têtes lectrices («pick-ups») est étudié de manière à mettre en évidence les spécifications essentielles relatives aux enregistrements de référence utilisés. Les caractéristiques techniques des nouveaux enregistrements étalons produits par Brüel et Kjær sont ensuite discutées et les méthodes de mesure associées sont décrites principalement sous l'angle de leur rapidité et automatisme d'emploi. Des exemples de résultats expérimentaux obtenus avec l'équipement standard B & K sont présentés en fin d'article.

ZUSAMMENFASSUNG

Nach einer Übersicht über die Wiedergabeverfahren für stereophonische Schallplatten werden Prüfprobleme von Stereophonie-Aufnehmern anhand der B & K-Frequenzgang-Meßschallplatten behandelt. Die neuen Meßschallplatten und die damit verbundenen Meßmethoden werden unter Berücksichtigung der rationellen Prüfarbeit eingehend beschrieben. Zum Schluß werden einige experimentelle Ergebnisse angegeben.

Introduction.

The fundamental superiority of stereophonic sound reproduction over the ordinary monophonic process is universally recognized and stereophony has become a common feature of mass-produced sound reproducing equipment.

Basically, the word "stereophonic" means that the sound is considered, in one particular location, not only in intensity but also in direction, i.e. a vector quantity is involved. This vector can be resolved in two components of fixed directions. Stereophonic sound reproduction consists in the recording, reproducing and transmitting of these components with their original amplitude and relative phase.

Conservation of the correct phase relation between the two components is of particular importance when considering the recording-reproducing process.

*) This article follows the Contributed Paper presented by the author at the 4th International Congress on Acoustics.

In the case of tape recorders, this is obtained without difficulty by recording the components on different tracks of the same tape. In the case of disk recording, however, the use of two grooves would rise a problem of correct tracking, and would at least halve the playing time, which is an unacceptable drawback for commercial use. For this reason, a rather delicate process is employed for stereophonic disk recording: this is called the 45°/45° process.

Here the two components of information are recorded in the same groove in two directions at 90° angle with each other and at 45° to the disk surface (Fig. 1). Physically, the two components of the original signal are picked up by two or more microphones, amplified separately, and then recombined in the recorder to give the cutting stylus, controlled by an electrodynamic device, a resulting velocity representing the amplitude and direction of the sound. The sound is reproduced stereophonically by tracing the groove on a copy of the recording with a suitable reproducing head, or "pick-up". The stereophonic pick-up resolves the movement of its stylus tip into two components at ± 45° to the disk surface and then transduces these components into electrical signals to be amplified through the two channels of the stereophonic reproducing chain.

Other methods of stereophonic disk recording have been developed, but the 45°/45° process described above is one of the simplest, and offers the great advantage of symmetrical conditions for both channels. It is now accepted and utilized the world over.

The 45°/45° process was proposed by Blumlein of Electrical and Musical Industries Ltd. already in 1932, together with a vertical-horizontal system which was the only system compatible with the vertical record players used at that time. Stimulated by the constantly increasing interest of the public for disk records, a considerable amount of research has since been devoted to the design of stereophonic disk recording and reproducing equipment. Recent results achieve a high degree of fidelity in recording, but good performance is more difficult to attain in the reproduction. One reason for this is that since at the present time commercial recordings are available on plastic materials with limited mechanical compliance, such as "Vinylite", it is essential for true reproduction that the loading of the record by the reproducing stylus by extremely small.[1] This means a correspondingly low mechanical input level for the transducing head and the necessity for high precision manufacture.

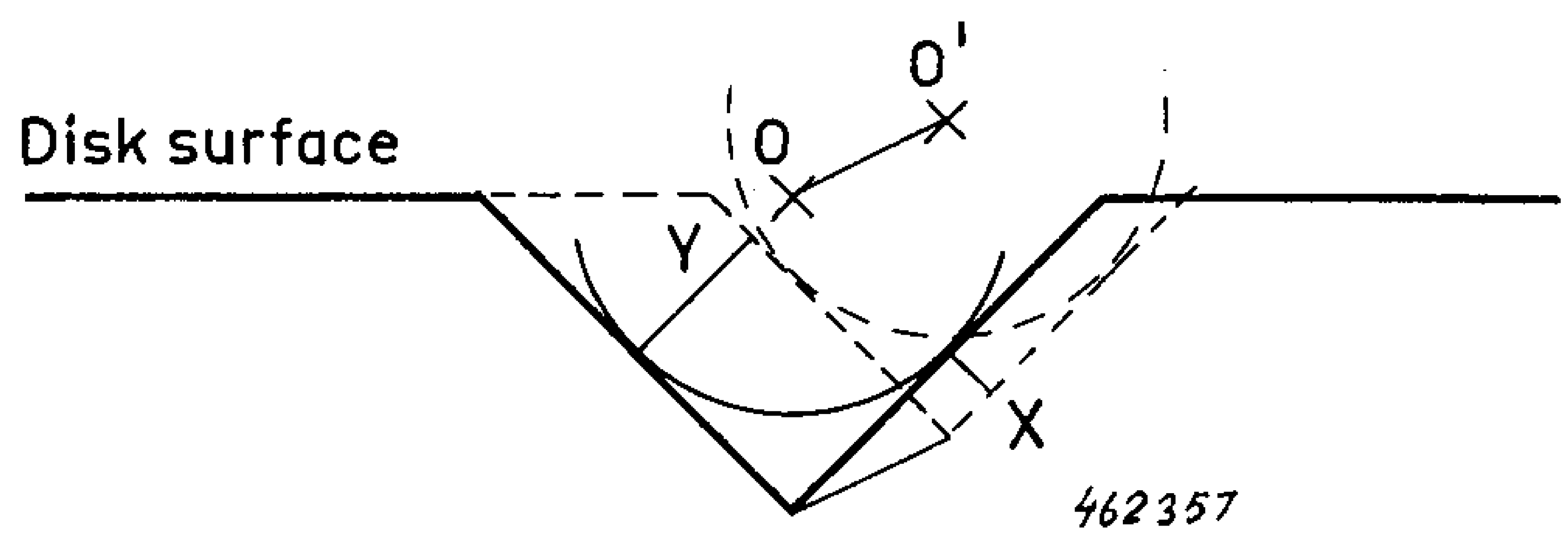


Fig. 1. Recorded displacement.

Reproducing pick-ups capable of following the best quality recordings available today without appreciable distortion have been designed and realised in laboratories. However, when considering pick-ups which are series produced at competitive price, important deviations from the prototype specification may often be expected.

The complete check of a stereophonic pick-up requires, as explained below, controlled variation of several parameters. The operation tends to be long and tedious if it is not made automatic, and consequently it is often neglected in serial production for economical reason. This renders any comparison between the nominal characteristics of different pick-ups rather doubtful and if high performances are claimed, individual precision test of stereophonic pick-ups is a necessity.

A demand has thus arisen for an automatic system to test disk reproducing equipment and especially pick-ups which usually are the weak link of "HiFi" chains, using the Brüel & Kjær audio frequency automatic response recorder. This equipment, whose accuracy and reliability in operation has been continuously improved, has been in production for about 15 years and has long been recognised as an excellent basis for any such test-system. This adaptation is now available, together with suitable calibrated gliding frequency recordings. The technical back-ground of these new recordings and some examples of applications are presented in the following pages.

Principles of Stereophonic Pick-up Test.

The stereophonic pick-up, considered as a mechanical-electrical transducer, presents a two-dimensional mechanical input and two electrical outputs. The ideal transfer function consists in the resolution of the two-dimensional input into two components along two axis making $\pm 45°$ to the disk surface, and the transducing of these mechanical quantities into proportional electric voltages. In practice this function will be dependent upon various parameters, the most important of which are here the amplitude and the direction of the mechanical input, and the frequency.

The amplitude of the mechanical input is characterized by the modulus of the two components of the instantaneous *velocity* (Fig. 2). For a sinusoidal excitation of definite direction, as used for the tests, the r.m.s. values of the velocity components can be employed. By calling these A and B respectively, the definition can be written symbolically:

$$\bar{V} = \sqrt{2}\,(A + jB)\sin \omega t$$

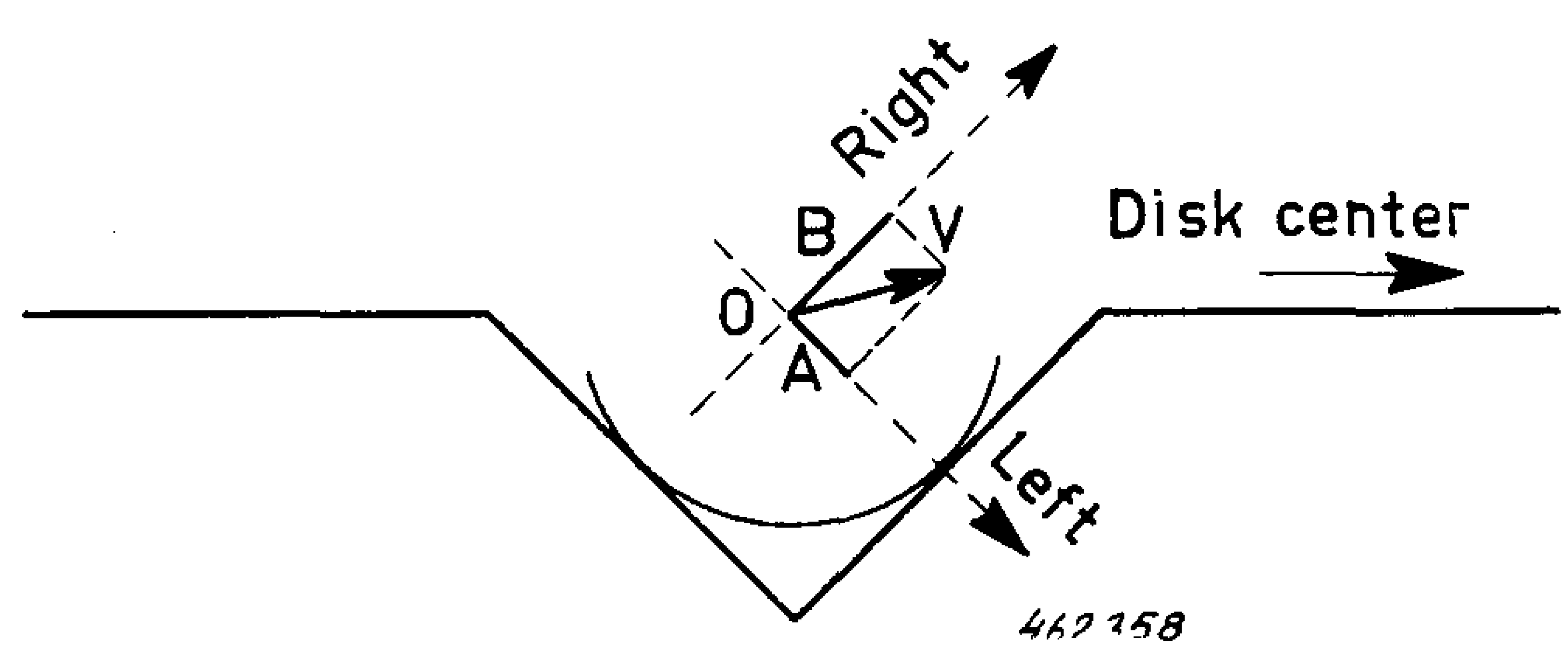


Fig. 2. Recorded velocity.

The inner and outer side wall of the groove are called "Left" and "Right" sides respectively and their modulations correspond to the left and right hand loudspeakers or recording microphones, as viewed from the audience.

A very important characteristic of a stereophonic pick-up is its frequency response, described for each channel by different curves for different directions of the mechanical input. Practically, it is sufficient to consider the curves relative to the four principal directions, i.e.: 45° left, 45° right, lateral (parallel to the disk surface), and vertical (perpendicular to the disk surface). The frequency range in which the response has to be determined should of course include the whole audible range and attain as high frequencies as possible for the determination of the stylus resonance. A range covering three decades (10 octaves), typically 20 c/s to 20 kc/s, is consequently desirable. Measurements under 20 c/s are also sometimes necessary for tone arm resonance investigation.
In addition to the frequency response of each channel, another important factor is the separation between channels. When exciting the stereophonic pick-up with a movement parallel to one of the axis of projection defined above, it is an essential condition that the component on the other axis should be equal to zero, or in practice that the cross-talk in the unmodulated channel be negligible with respect to the modulation in the other channel. This property which is called the separation between channels, is in fact the basis of stereophony and it is essential to control it accurately throughout the audible range and if possible at different modulation levels. It happens quite often that it is satisfactory only in a small part of the audible range for mass-produced pick-ups, and sometimes it has only been controlled at one fixed frequency, e.g. 1000 c/s. Separation is usually expressed in decibels:

$$S\ (\text{db}) = 20 \log_{10} \frac{A}{b}$$

$$S'\ (\text{db}) = 20 \log_{10} \frac{B}{a}$$

by calling b, or a, the r.m.s. cross-talk signal in the unmodulated channel when the other channel is carrying a signal of r.m.s. value A, or B, respectively. Separation is generally considered as satisfactory when over 20—30 dB (i.e. the cross-talk signal is less than a few percents of the main signal).
The behaviour of the stereophonic pick-up as a function of amplitude, i.e. the dynamic properties, is investigated by means of calibrated recordings of fixed frequency and varying amplitude. However, these properties are generally not critical, regarding only the pick-up, since the harmonic distortion in the pick-up is normally much lower than the inherent tracing distortions.[2, 3]

Finally, a parameter inherent in disk reproduction should be mentioned: the groove speed, which is continuously variable from the periphery to the center of the disk, in the proportion of 2.5 to 1 for 30 cm (12″) records. However, the influence of the groove speed is mainly a matter of relative magnitudes of the mechanical curvature of the recorded signal and of the stylus tip radius, the latter being fixed within rather narrow limits by the standards and usually pre-checked accurately by optical methods. There exists nevertheless a relationship between the influence of the groove speed on the response and the mechanical impedance of the input. A check at various groove speeds is therefore useful for controlling this impedance, if correct interpretation is available. See Appendix A.
All of the previously mentioned characteristics should be known for assessing the quality of a stereophonic pick-up. Furthermore, both channels should behave identically. Appreciable deviations in frequency response for example would cause some phase distortion when the stereophonic sound is reconstituted at audition.

Reference Test Records.
The different characteristics outlined above are conveniently checked by using calibrated disk recordings of sinusoidal tones covering the frequency range of interest and with different directions of modulation. These recordings are obtained on specially selected recording equipment, with the maximum care, from the output of a precision audio generator. See Appendix B.
If the pick-ups to be tested are intended to be used for reproducing commercial records, the test records should be manufactured out of a similar material. The elastic properties of the "Vinylite", which is so far very generally employed, play a certain role in disk reproduction. This is easily understood when considering that the acceleration which is communicated by the record to the stylus tip is of the order of a few hundred g for the higher tones, and quite often presents peaks of more than 1000 g. Even if the stylus mass is reduced to a minimum, the reaction of the stylus on the record causes non-negligible elastic deformations or resonances which should be taken into account in the pick-up response (play-back losses).[4, 5, 6]
Vinyl-records have the drawback of a limited service life, but this is compensated by the low cost and the availability of advanced techniques for copying and pressing.
Reference recordings can be realised in different ways. The most obvious is to record a fixed sine tone of constant frequency and constant amplitude and to rotate the disk at variable speed. This enables quick checks to be made in limited frequency ranges, but does not allow actual measurements because of the difficulty of controlling a variable speed with sufficient accuracy. Records containing a series of various spot-frequencies, with announcement (vocal or coded) of the recorded values, are also employed but their use is rather tedious because of the necessity of taking a great

number of measurements through the whole frequency range in an effort to detect irregularities. These records are often used in laboratory for design work, but for the production testing of pick-ups, which is the subject of the present article, gliding frequency recordings are preferable. They provide a continuous frequency sweep at a controlled level and known rate which enables complete plotting of the frequency response and precise separation measurements at all frequencies. The gliding frequency test is a time-saving feature both in the design and control of stereophonic disk reproducing equipment.

A survey of the characteristics of stereophonic gliding frequency test records follows with the description of the new test records produced by Brüel & Kjær.

The B & K Stereophonic Gliding Frequency Records.

The B & K reference recordings are cut in accordance with the international recommendations of the IEC[7] and are pressed in "Vinylite". The label of the Type QR 2009 is reproduced in Fig. 3. Each side of this record consists of two groups of four bands, each group containing as illustrated in Fig. 4:

Fig. 3. Reproduction of the label of a test record.

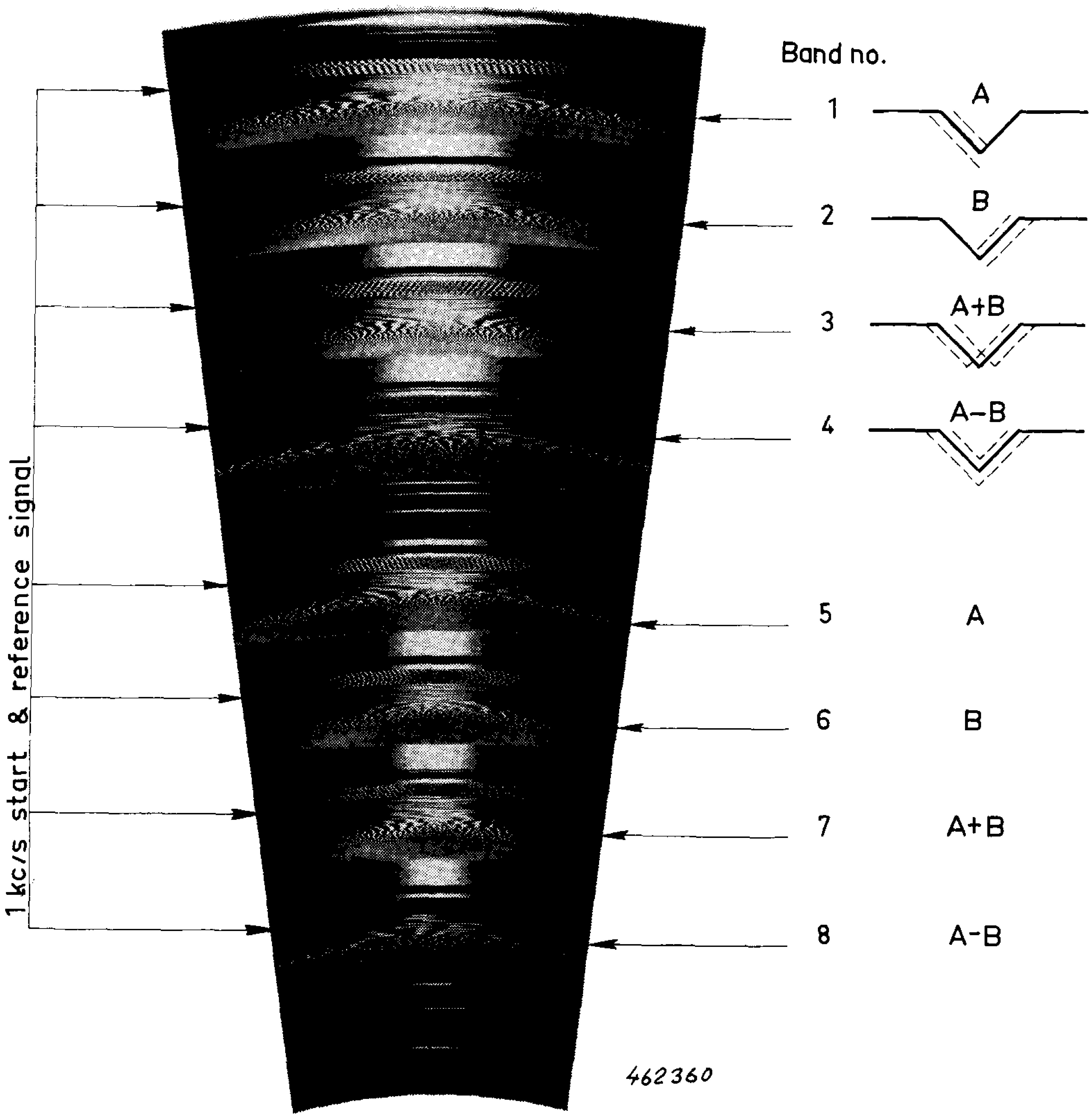


Fig. 4. Section of B & K Stereophonic Gliding Frequency Record Type QR 2009. The succession of the different reference recordings is clearly observed with the aid of a grazing parallel light beam. Each band is preceeded by a constant frequency modulation giving a mean of determination of the start point of the frequency sweep, and succeeded by an unmodulated period corresponding to the dead part of the recording paper charts of the Level Recorder Type 2305.

(1)	a 45°-left modulation	band	(A,	B = O)
(2)	a 45°-right modulation	band	(A = O,	B)
(3)	a lateral modulation	band	(A,	B = A)
(4)	a vertical modulation	band	(A,	B = —A)

The notations A = B and A = — B correspond to the fact that the lateral modulation is obtained by equal and in-phase modulations of each channel, whilst vertical modulation results of equal and anti-phase modulations.

Only one parameter varies from one group to the other: the groove speed,

or recorded wave-length, which is reduced by 35—40 % in the inner bands with respect to the corresponding outer bands.
Lateral modulation bands are also available on the "Monophonic" Gliding Frequency Records Type QR 2007 which are cut in the same ways as the QR 2009 but only with lateral modulations (ten A = B bands are available on each record side). The maximum groove bottom radius is 5 μ as specified by the standards and the QR 2007 may thus be used for testing the lateral response of stereophonic pick-ups. It will therefore be mentioned in the following description with regard to this particular use.
Each band covers the frequency range 20 c/s — 20 kc/s with a true logarithmic scanning when the record is rotated at the constant speed of 45 r.p.m. This logarithmic sweep is produced by a B & K Beat Frequency Oscillator whose frequency accuracy, with respect to a pure logarithmic time function, is 1 % $\pm$ 1 c/s $\pm$ o.7 degrees, corresponding to $\pm$ 2.2 % $\pm$ 1 c/s. The higher groove speed provided by the 45 r.p.m. — instead of normally 33⅓ r.p.m. for records of this size — enables a better measurement accuracy to be obtained at high frequency, or a correspondingly larger amplitude to be recorded. Actually, the recording is carried out at reduced speed, with a modified oscillator, in order to make the most of the disk recording equipment. See Appendix B.

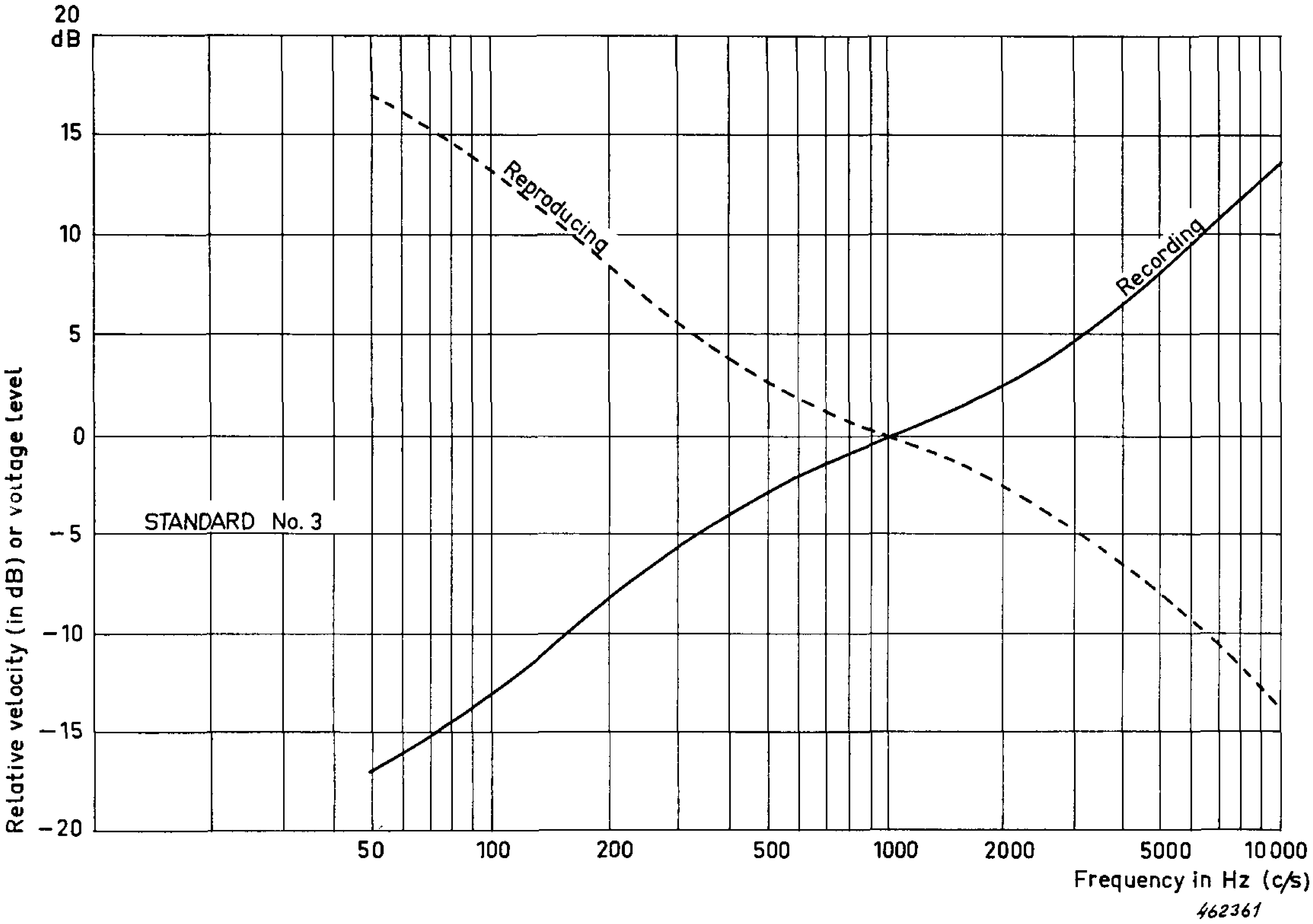


Fig. 5. The standard stereophonic disk records velocity characteristics as illustrated in IEC Publication No. 98. Extension towards lower or higher frequencies is obtained from the mathematical definition cited in the text.

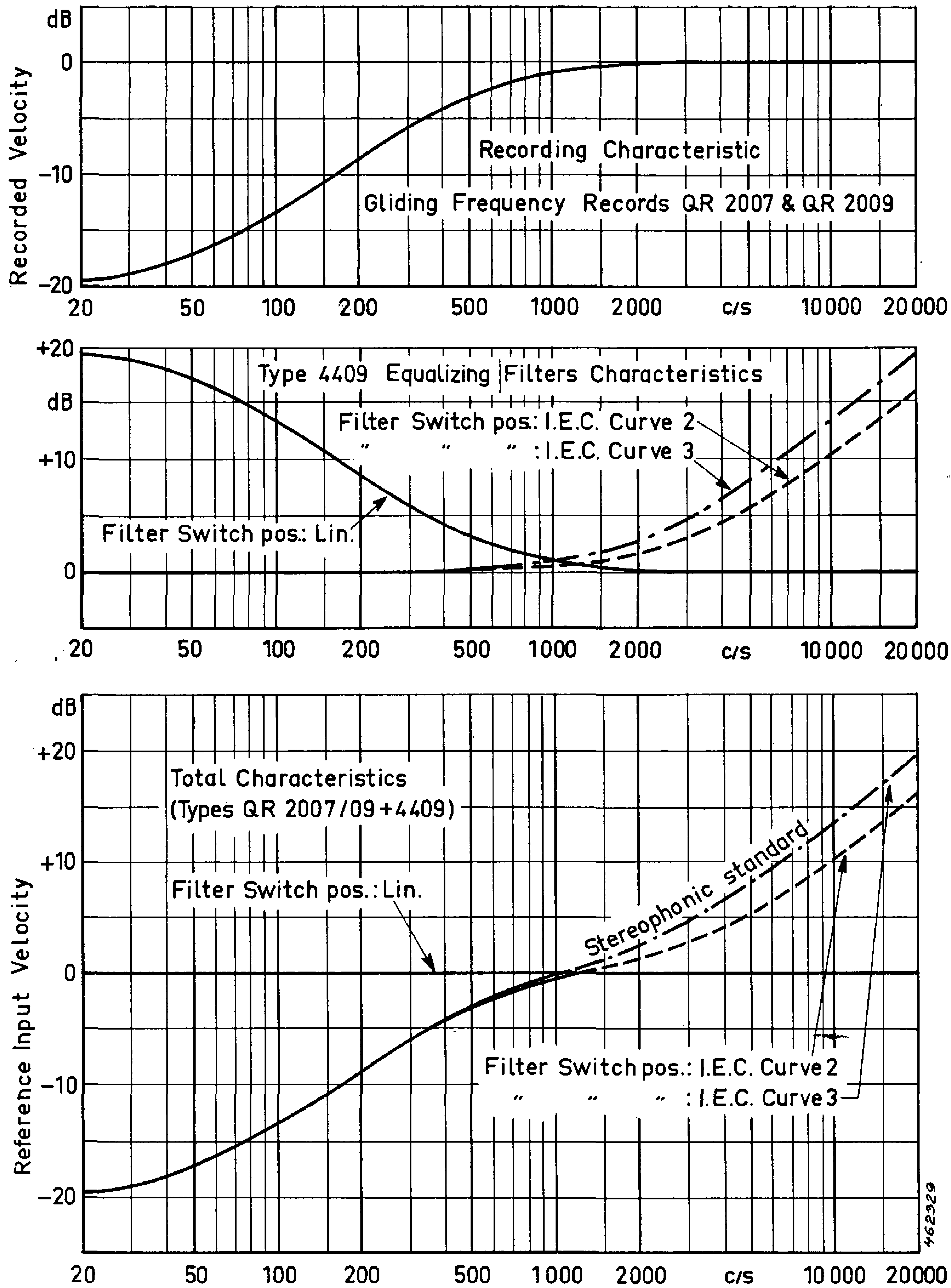


Fig. 6. In addition to the standard characteristic No. 3, the B & K equipment provides the slightly different characteristic No. 2 which is optional for monophonic reproduction, and a constant velocity characteristic.

Stereophonic pick-ups should be tested with reference to the internationally recognized characteristics No. 3 recommended by the I.E.C.[7], if they are intended to give constant output as a function of frequency. Gliding frequency records should in general be cut according to this recording characteristic shown in Fig. 5. In the case of the B & K Gliding Frequency Records, a characteristic as shown on top of Fig. 6, which is converted by an equalizing filter in the measuring chain to the appropriate characteristics, has been adopted. The reason for the high frequency level limitation on the record is that if true reproduction is intended, the radius of curvature of the modulated groove wall must remain appreciably larger than the stylus tip radius.
The wave-length being determined by the chosen groove speed, and the stylus tip radius being normalized to 15—18 μ for stereophonic pick-ups, this sets a maximum limit to the amplitude of modulation at high frequencies. The conditions obtained on the B & K Gliding Frequency Records, where the recorded velocity is limited at 20 kc/s to 3.5 cm/s peak in each channel, are illustrated in Fig. 7.
The advantage of the standardized recording characteristic is to give the optimum signal-to-noise ratio by increasing the recorded amplitude at low frequencies, where the rumbles and vibrations of the turntables are important, and the recorded velocity at high frequencies where the surface noise increases rapidly. Using any other characteristic will result in a

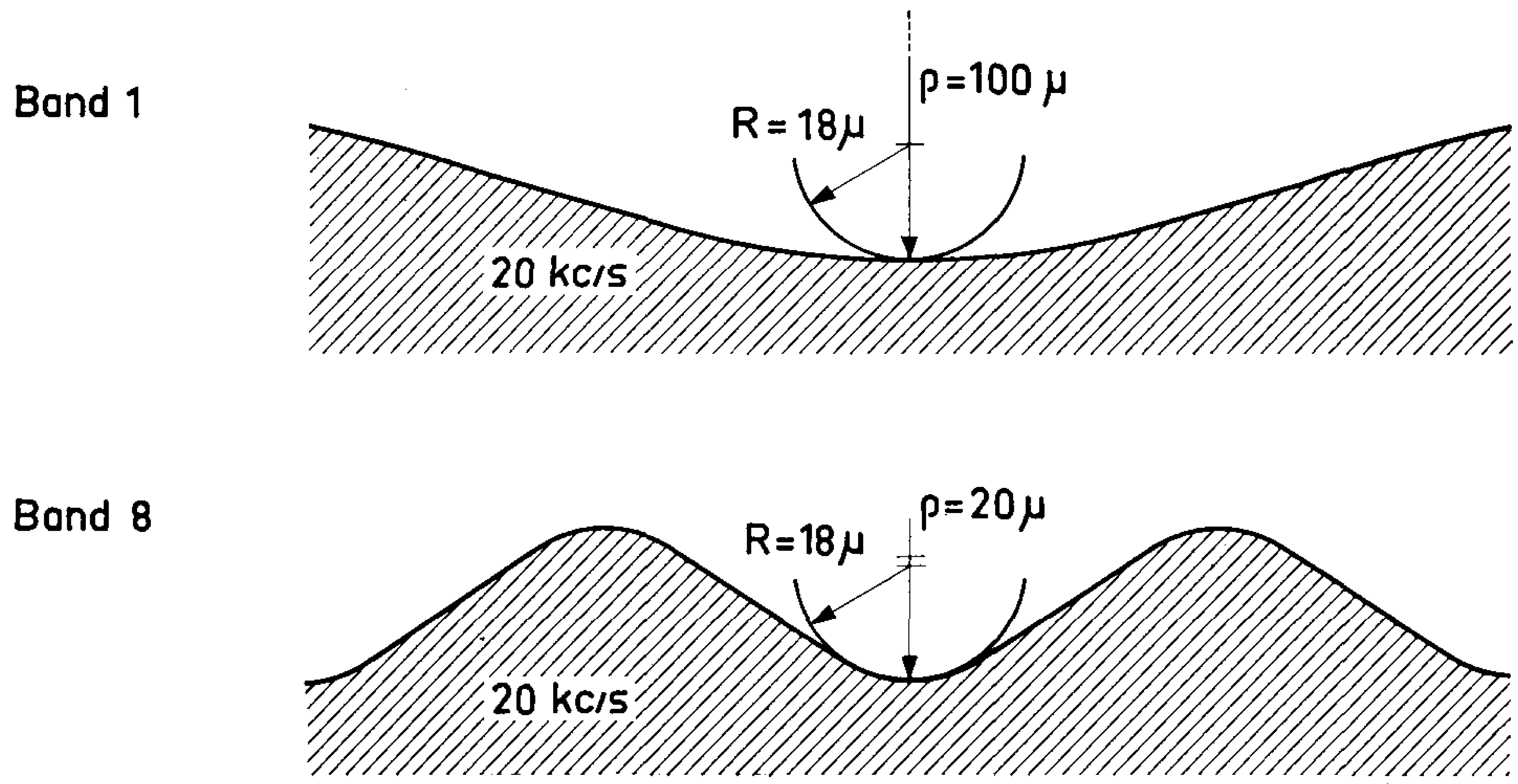


Fig. 7. Views in the plane of modulation showing the relative dimensions of the maximum allowed tip radius and the minimum radius of curvature ϱ on the record QR 2009's outer and inner bands presenting a diameter of 28.2 and 12.6 cm respectively at 20 kc/s. Note that ϱ is proportional to the square of the diameter D (or of the groove speed). The speed of rotation being 45 r.p.m., i.e. 0.75 r.p.s., the expression of ϱ is

$$\varrho = \frac{\pi\,(0.75\;D)^2}{2\,FV} = 0.88\;\frac{D^2}{FV}$$

where F is the frequency and V the peak channel velocity (3.5 cm/s).

decrease of the overall signal-to-noise ratio after correction of the characteristic by an equalizing filter. In the case of the B & K Gliding Frequency Records the signal-to-noise ratio is decreased by about 6 dB after equalization, but this does not affect the measuring possibilities.

In addition, the correction of the recording characteristics can be made easily by means of a simple RC filter. Using different filters enables the selection of different characteristics. This is of interest since there are differences between the various national standards. Using a suitable filter, a constant recorded velocity reference can also be obtained for testing electrodynamic pick-ups without their associate equalizers. Three different characteristics are thus provided by the B & K measuring equipment. See Fig. 6. The determination of the correcting filters results immediately from the mathematical definition of the standard characteristics[7]:

$$10 \log (1 + \omega^2 t_1^2) - 10 \log \left(1 + \frac{1}{\omega^2 t_2^2}\right) + 10 \log \left(1 + \frac{1}{\omega^2 t_3^2}\right)$$

where ω is the angular frequency and

$t_1 = 50\ \mu s$ (curve 2) or $75\ \mu s$ (curve 3), $t_2 = 318\ \mu s$, $t_3 = 3180\ \mu s$.

The recording characteristics of the B & K test records corresponds to

$$t_1 = 0,\ t_2 = 318\ \mu s,\ t_3 = 3180\ \mu s.$$

The frequency scanning rate in each band of the QR 2009 is 4/15 octave per revolution corresponding at 45 r.p.m. to 5 seconds per octave, or 50 seconds for the whole sweep 20 c/s — 20 kc/s. In addition, as seen on Fig. 4, each band is preceeded by a 1 kc/s start and reference signal lasting approximately 7 seconds. The 20 c/s point of the logarithmic sweep coincides with the end of the 1 kc/s modulation. The purpose of this 1 kc/s signal is in addition to the determination of the frequencies in the results as described below, to allow a quick adjustment of the measuring chain sensitivity to be made before actual measurements are taken.

The accuracy in amplitude of the reference recordings is determined to within o.5 dB in a limited frequency range by the optical method of the "Filtered B-line light pattern" referred to in the American Standards [8, 9]. Over the whole frequency range, the accuracy is checked by means of a professional electrodynamic pick-up especially selected for this purpose. The check is carried out at two different rotation speeds in order to distinguish the non-linearities of the pick-up from those of the record itself: a change in rotation speed accompanied by a corresponding change of the time constant of the equalizing filter produces a frequency translation of the record defects, while the frequency response of the pick-up is unchanged. The investigation is carried out both on the nickel "mother" and on the vinylite records.

The flatness in frequency characteristic obtained in serial production is better than ± o.5 dB from 100 c/s to 10 kc/s and ± 1 dB from 20 c/s to 16 kc/s. Between 16 kc/s and 20 kc/s a dip in the frequency response which is due to a spurious resonance in the disk recorder might be present and the tolerances are therefore enlarged, as shown on Fig. 8.

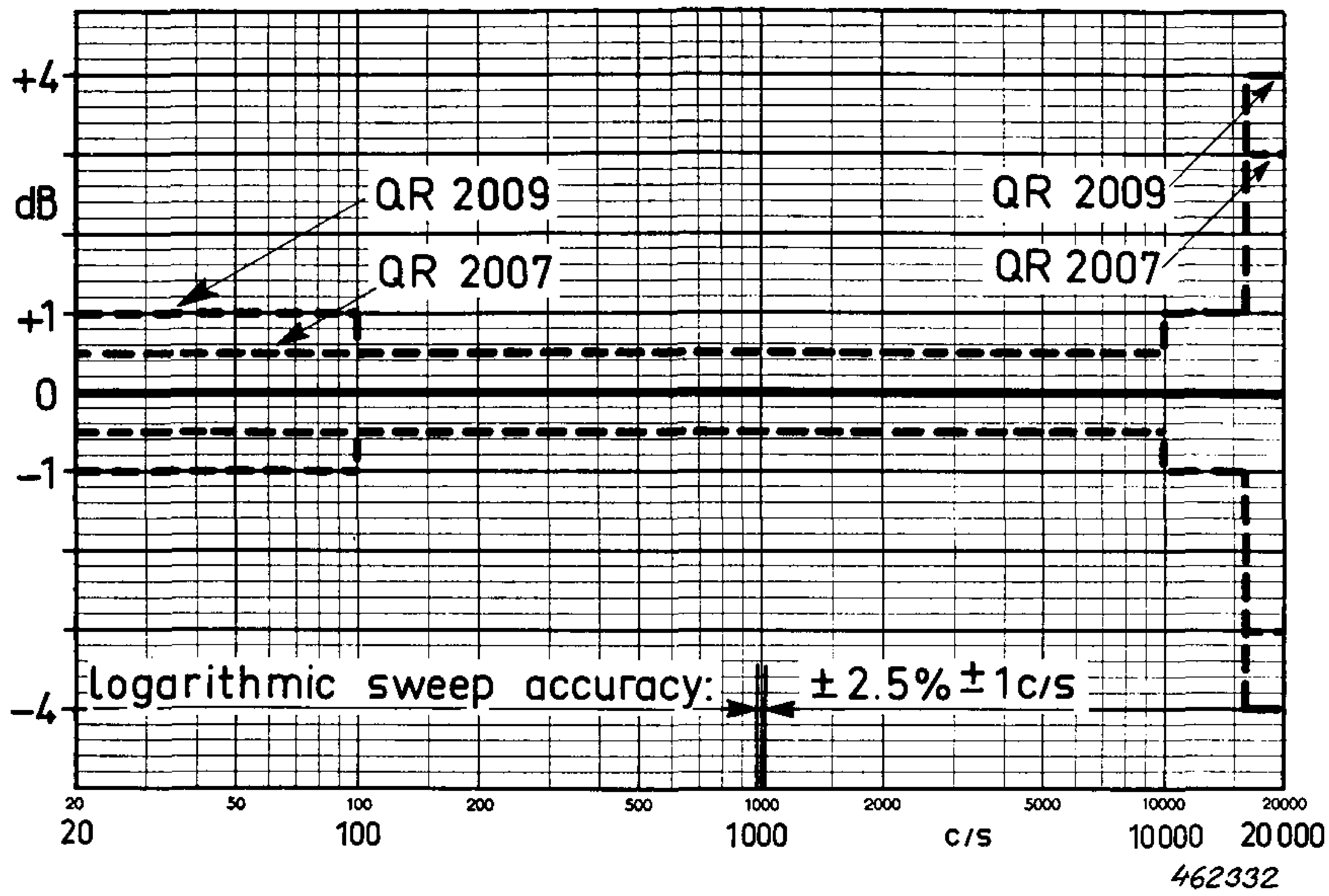


Fig. 8. Recording characteristic tolerances including the record and the equalizing filters characteristics. The accuracy is best in lateral modulation and the tolerances are therefore narrower for the QR 2007 (See also Fig. A 3 in Appendix).

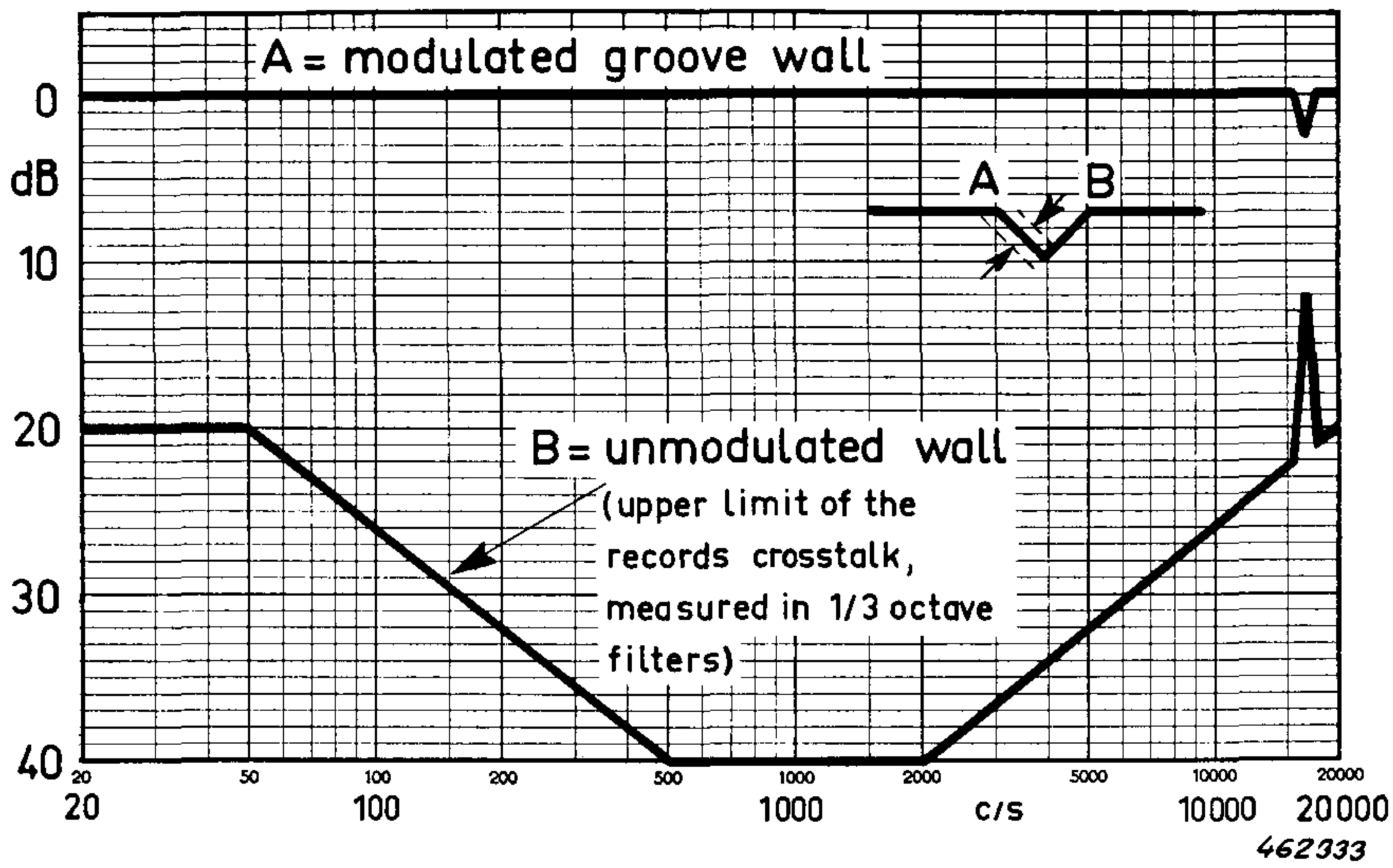


Fig. 9. Maximum limit of the allowed recorded cross-talk on the stereophonic recordings Type QR 2009, bands 1—2 and 5—6, measured in dB with respect to the recording level (i.e.: maximum measurable separation).
N.B. Valid only when the playing angle does not deviate much from the cutting angle (10° ± 5°).

Another important characteristic of the stereophonic test record is the upper limit of the recorded cross-talk on the unmodulated groove walls of bands A and B. This corresponds to the separation of the disk recorder since it is practically unaffected by disk copying operations. The determination of the spurious cross-talk in the pick-up employed for checking the recorded cross-talk can also be made by comparison between two tests at different rotation speeds, giving a frequency translation of the characteristic for the record only. The recorded cross-talk expressed in dB with reference to the modulation level is the separation between channel of the recording. The minimum separation of the QR 2009 is shown on Fig. 9.

Automatic Frequency Response Plotting.

The monitoring of the output from the pick-up tracing the test record is most conveniently made by means of a level recorder with a paper speed of a few mm per second. The beginning and the end of the logarithmic frequency sweep appear clearly, and a logarithmic master scale covering three decades of appropriate length can be superimposed on the recorded curve for reading of the frequency. The Record Type QR 2009, however, has been designed with a sweep time of exactly 50 seconds in order to fit with the preprinted frequency calibrated paper of the B & K Level Recorder Type 2305. This paper is calibrated on the basis of 50 mm per decade and the paper speed of 3 mm/sec provided by the 2305 gives identity with the scanning rate on the record. In addition, it is possible by an electronic device to command the start of the paper drive of the Level Recorder Type 2305 at the instant where the 1 kc/s start signal ceases, i.e. at the 20 c/s point, thus automatically ensuring synchronism between the instantaneous test frequency on the record and the frequency graduations on the recording paper. By this means, a calibrated chart of the pick-up test is obtained automatically, with all the associated advantages, especially repeatability and rapidity.

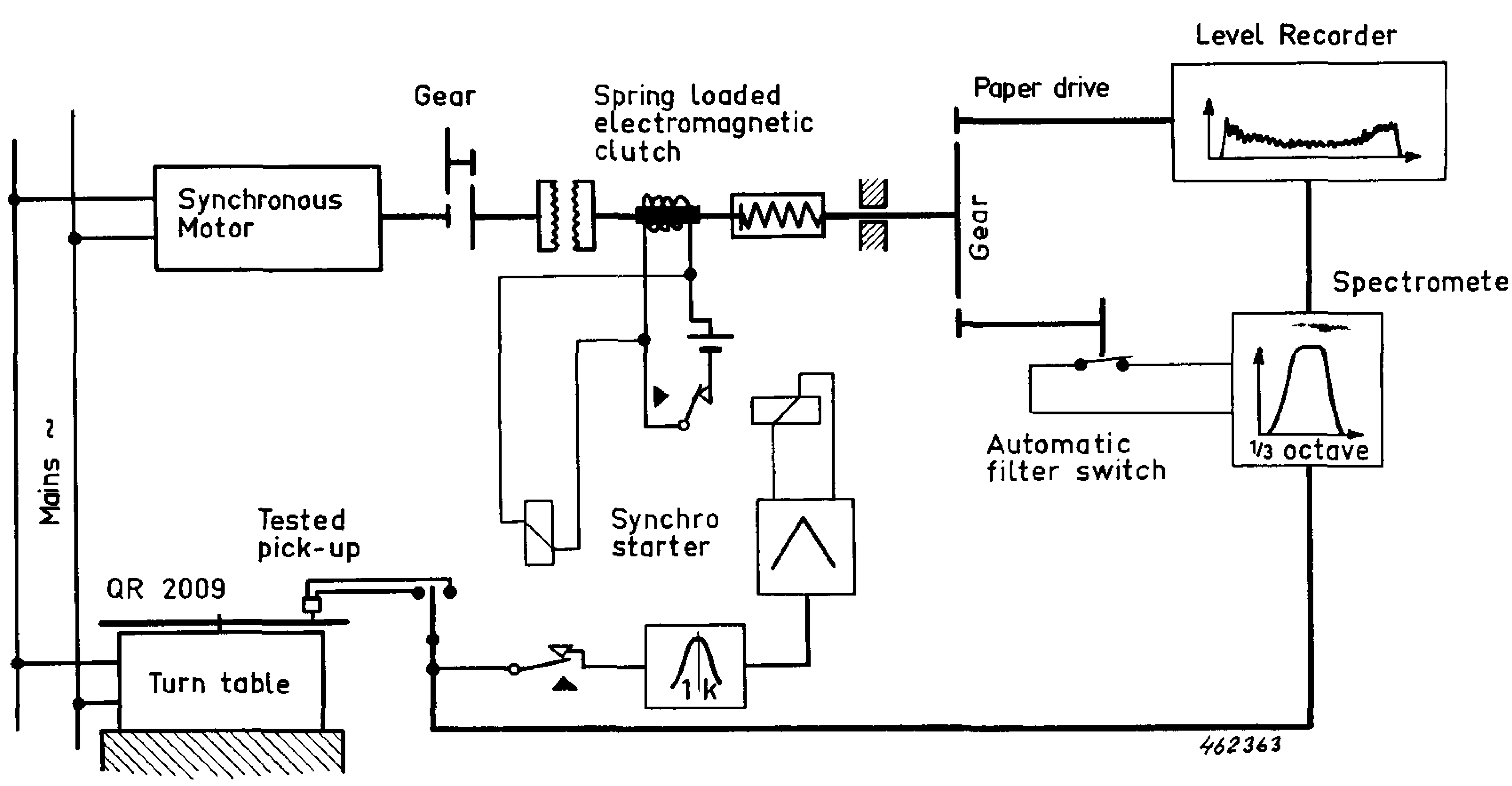


Fig. 10. Schematic diagram of the equipment for automatic frequency response and separation measurements.

An important point for the practical feasibility of this synchronization is that the time delay of the paper drive start should be negligible. A thorough description of the electromagnetic clutch of the paper drive of the Level Recorder Type 2305 will be found in the instruction manual for this instrument. This clutch, as schematically represented in Fig. 10, is engaged when no current passes through it and disengaged when excited.
It is a non-slip device and, since the coupling of the paper drive system to the continuously rotating synchronous motor introduces a negligible variation of kinetic energy in the system, the start of the paper drive occurs practically instantaneously when the current is cut. The command is thus made from the signal recorded on the test disk, by simply actuating a relay device cutting the clutch circuit at the end of the start signal. Such a relay arrangement is provided in the new B & K unit Type 4409. See Fig. 11. The scanning speeds of both the disk turn-table and the level recorder paper drive are tied by the mains frequency and no mechanical connection is needed. This allows the turn-table to be installed freely on an antivibration support which is an important point for precise measurement.

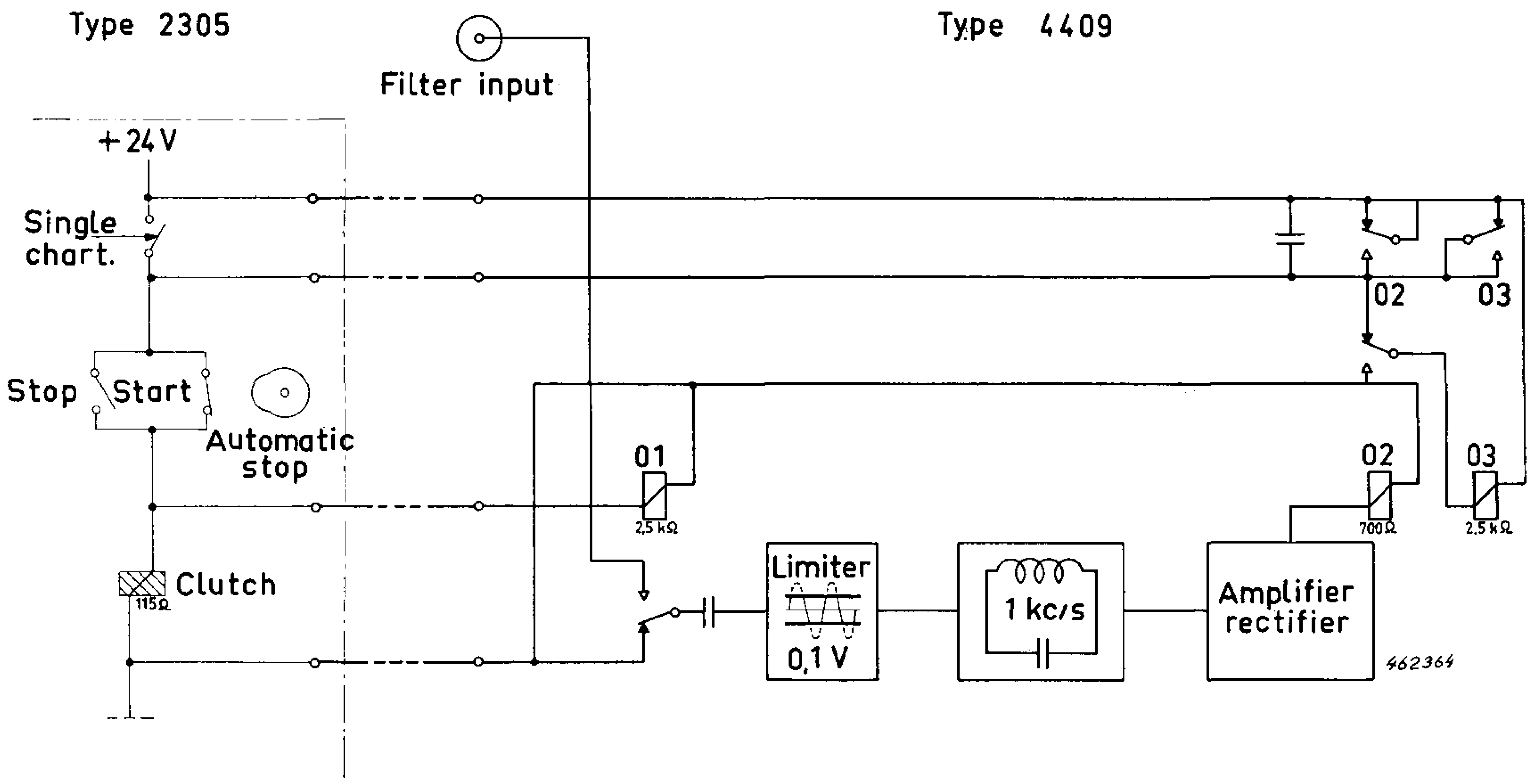


Fig. 11. Block diagram of the automatic start/stop arrangement. (Synchro-starter of 4409 + clutch circuit of the 2305).

In the same unit as this "synchro-starter" are mounted the RC equalizing filters giving standardized recording characteristics as described earlier, and a two-channel selector, driven from a multivibrator, enabling the simultaneous recording of the level in the two different channels to be made on the Level Recorder. The connections between the different part of an elementary measuring arrangement are seen on Fig. 12.
When only the lateral response of a stereophonic pick-up is to be tested, the measuring time may be reduced to a third by utilizing the Monophonic

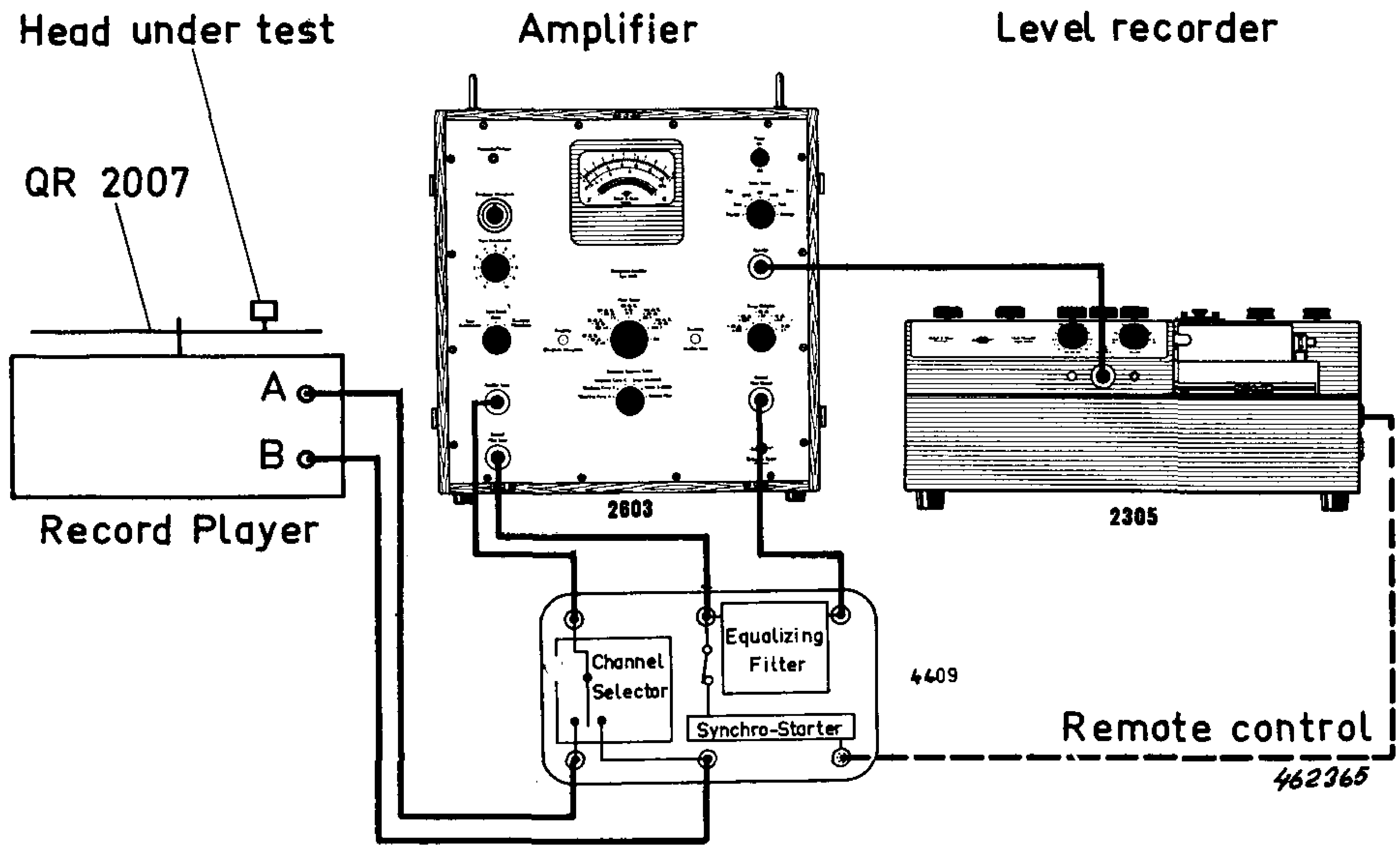
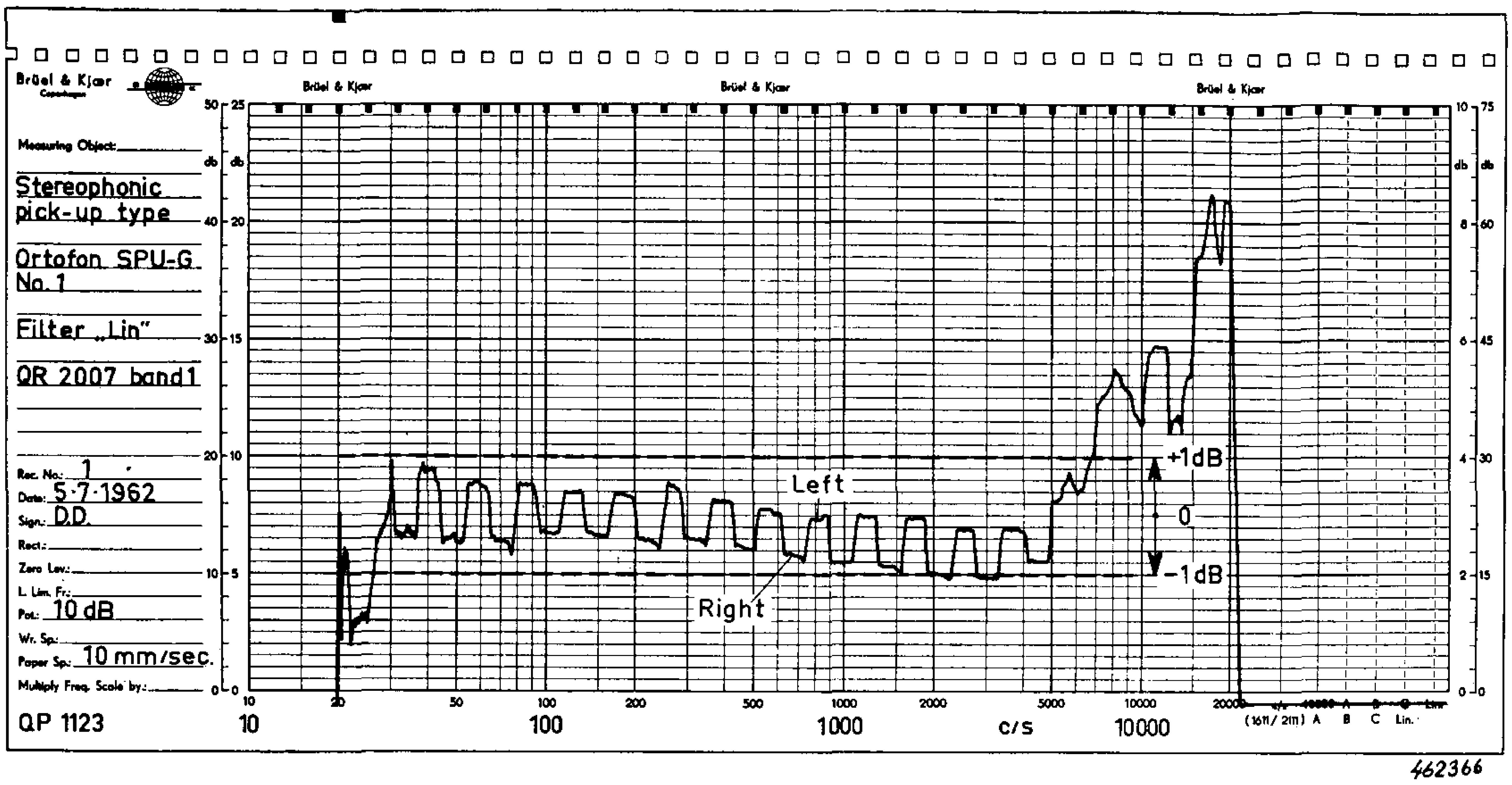


Fig. 12. Measuring set-up for automatic recording of the frequency response only.

Gliding Frequency Record Type QR 2007. As seen above, this record is cut in the same way as the QR 2009, with the exception of the frequency scanning rate which is 3.3 times quicker, corresponding to the 10 mm/sec paper speed of the Level Recorder. In these conditions the frequency sweep lasts only 15 seconds and the total duration of the test is 35 seconds between the instant when the pick-up is put down on the record and the instant when the set up is ready to start a new plot. In addition the two channels can be checked simultaneously by using the automatic drive of the two-channel selector having a frequency of 1 to 1.2 c/s. A hundred pick-ups can thus be tested in one hour by one non-qualified worker. An example of individual results obtained by this method is shown in Fig. 13.
However, the complete check of a stereophonic pick-up should include separation measurements for both channels throughout the frequency sweep. This can only be done by using the QR 2009 test record and takes a longer time, but the operation is also automatic as described in the following.

Automatic Selective Cross-talk Measurements.
The simple set-up of Fig. 12 presents a signal-to-noise ratio of around 20 to 26 dB depending on the groove speed and the characteristics of the pick-up under test. This seriously limits its use for automatic cross-talk measurements since very often the cross-talk will lie below the noise level*).

*) It is still important to check spurious signals well below ambient noise because of the selective properties of the ear.



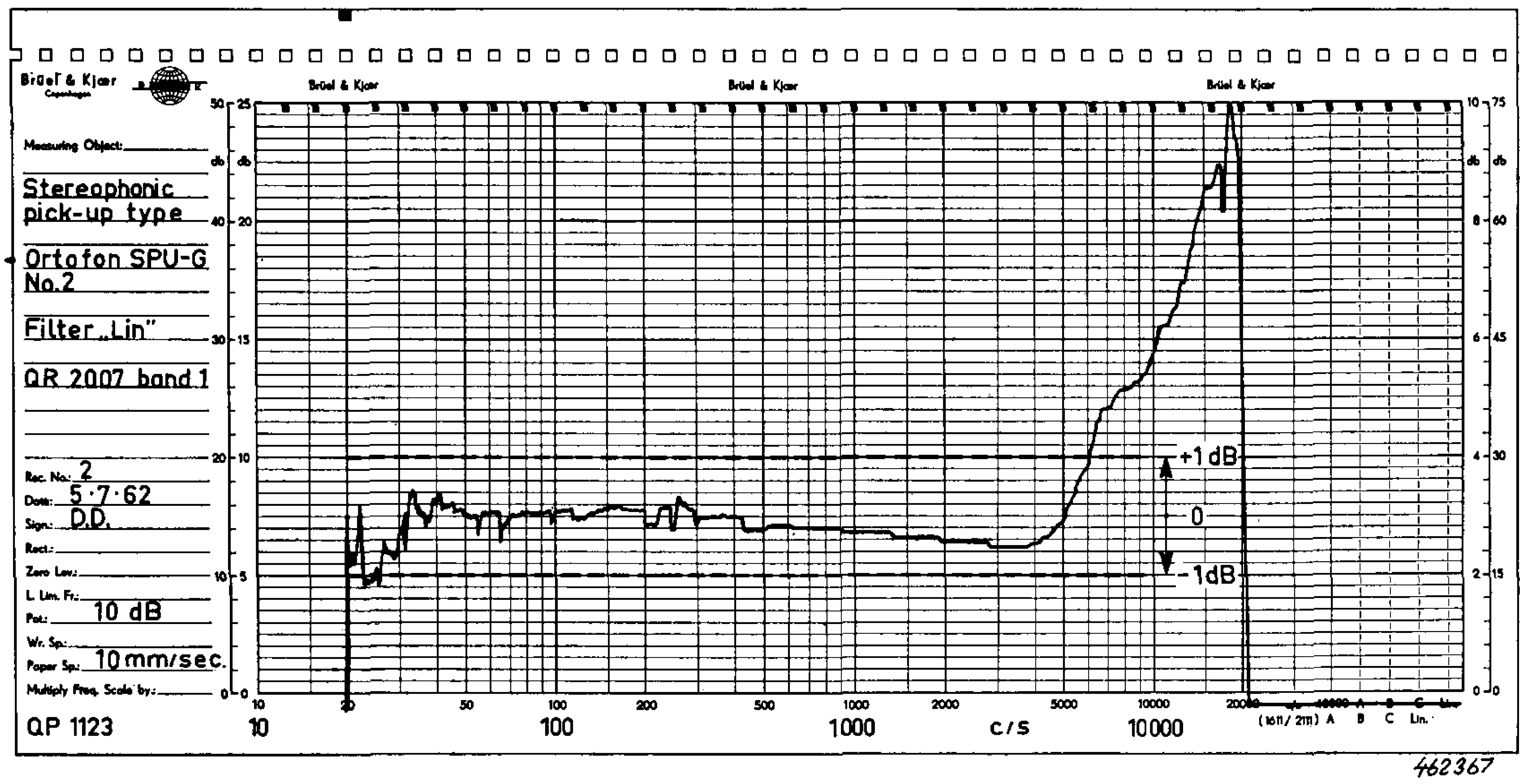


Fig. 13. Example of automatic frequency response and balance check carried out by means of the set-up of Fig. 12.

(1) High-grade stereophonic head presenting a certain unbalance.

(2) Head of the same type, with good balance between channels.

The measurement is taken alternately on either channels with individual measuring periods of approximately 0.4 second.

Increasing the signal-to-noise ratio by 6 dB by deleting the equalizing filter would be satisfactory only in a few cases and only for frequencies above 1000 c/s. Moreover, any worthwhile reduction of the noise by improving the disk recorder tends to be expensive and difficult to achieve. Nevertheless an effective solution for high separation measurements is to filter the

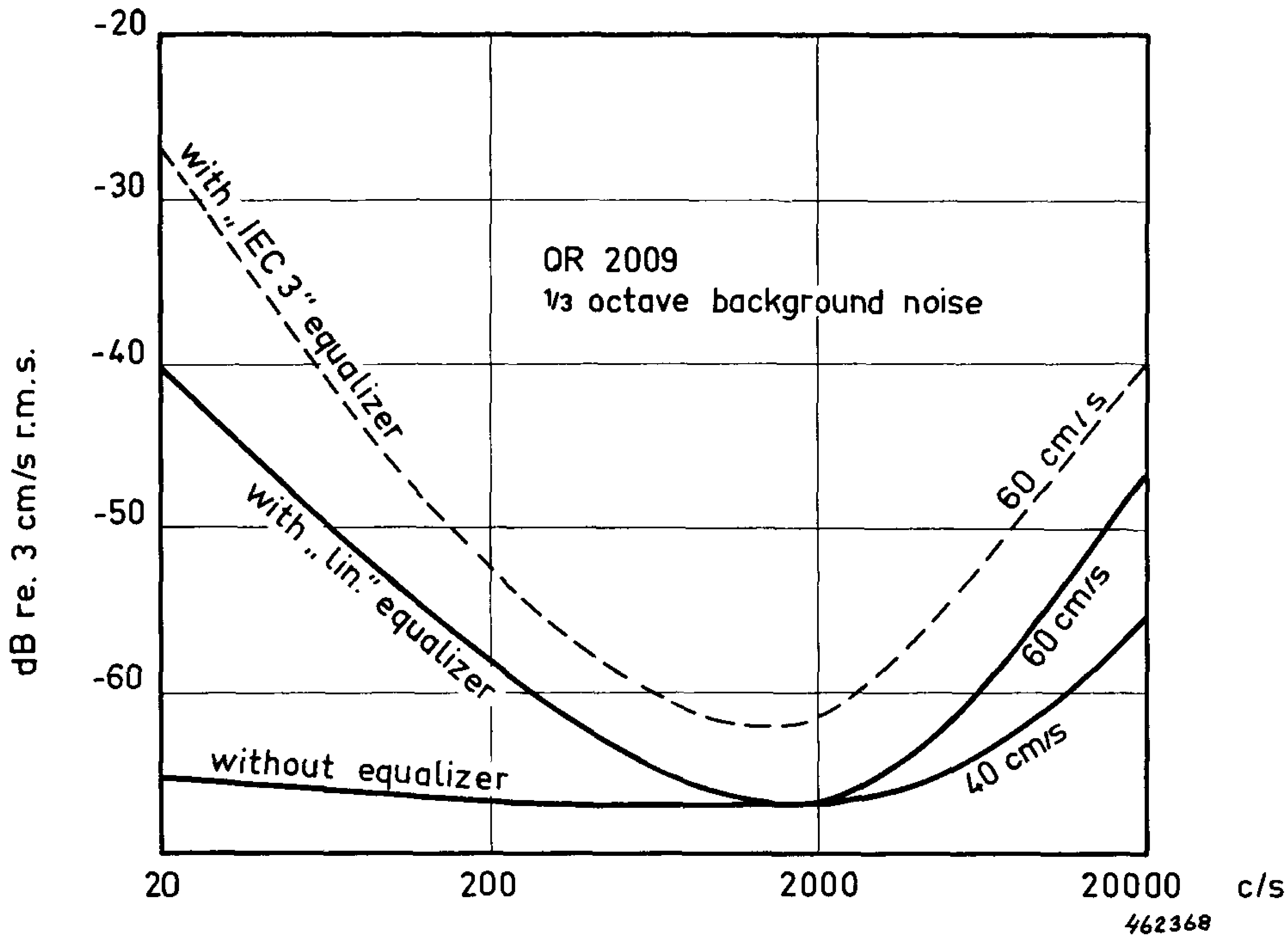


Fig. 14. Third-octave analysis of disk recording noise in typical cases. Full line: electrodynamic pick up Dotted line: piezo-electric pick-up. N.B. Lower noise levels may be observed with pick-ups presenting too great stylus mass and tip radius.

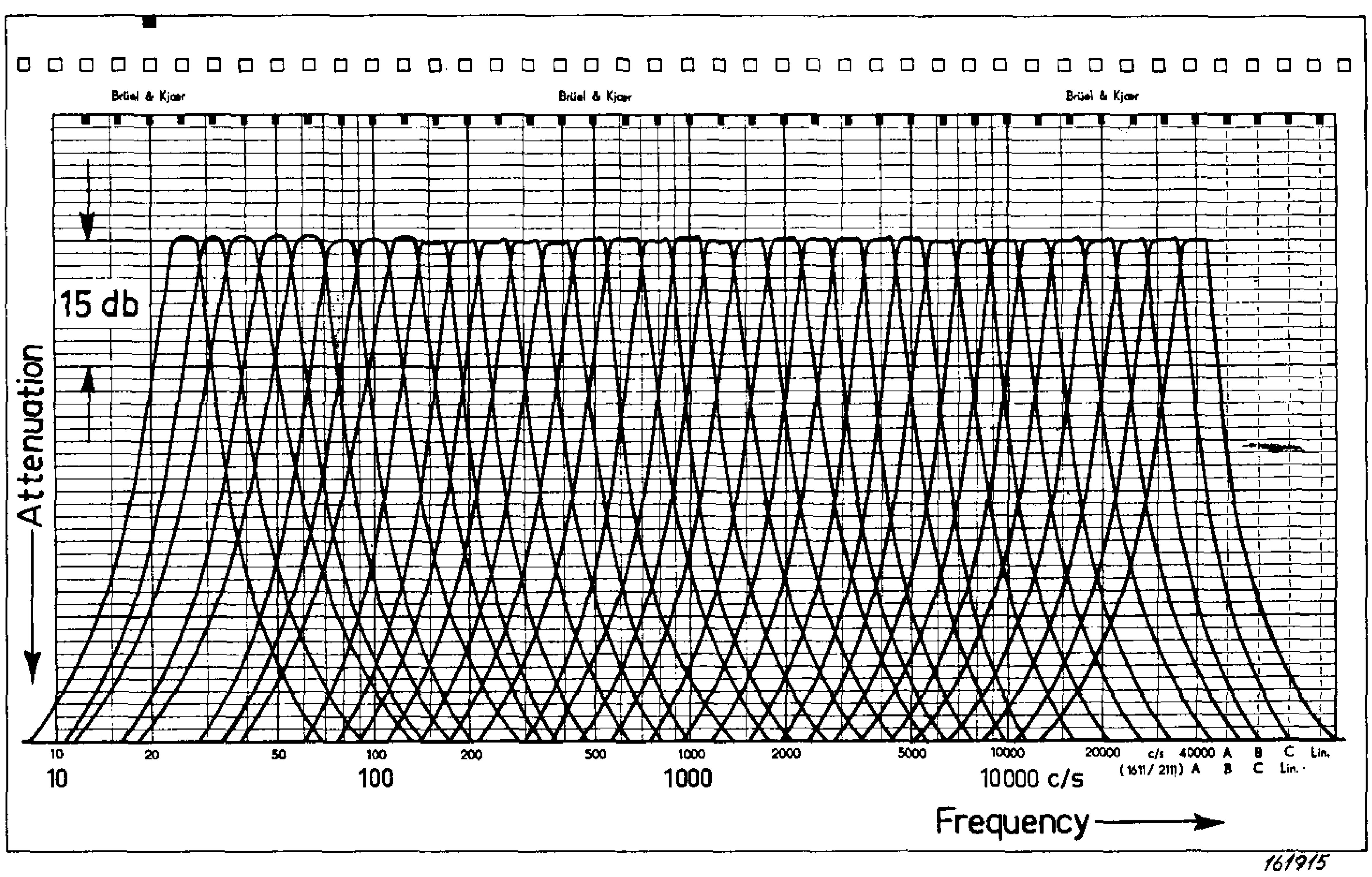


Fig. 15. The series of third-octave filters of the Spectrometer Type 2112 or Filter Set Type 1612.

noise in third octave filters such as those used in sound analysis. The signal-to-noise ratio is of the order of 60 dB in such filters as seen in Fig. 14. The overall characteristic of the series of 1/3-octave filters incorporated in the B & K Spectrometer Type 2112 is shown on Fig. 15. This instrument is particularly well suited for the purpose since its filter-switch can be driven in synchronism with the Level Recorder Type 2305. A measuring arrangement for automatic selective cross-talk plotting is shown in Fig. 16. If the cam actuating the Spectrometer remote control has a suitable position with respect to the automatic stop cam of the Level Recorder, the switching-in of the first filter occurs exactly when the frequency on the record is equal to the low limiting frequency of the filter (22 c/s). The filtering will then continue synchronously since the filter series is also logarithmic. Small frequency deviations are liable to occur, which are mainly due to the frequency error on the record and eventually a small rotation speed deviation. Since the adjacent filters are overlapping at 3 dB $\pm$ 1 dB down, the amplitude of the negative dips in the frequency response at filter switching points can attain 2 to 6 dB according to the fact that the filtered signal frequency is determined within $\pm$ 2.5 %. At the beginning of the sweep, where the 1 c/s absolute error is significant, the dips may present a still higher amplitude. This is seen in Fig. 17 where also the frequency response has been plotted with synchronous filtering.
In addition to the cross-talk the Spectrometer can be used for measurement of the harmonics in both the test signal and the cross-talk. By shifting the filter switch of the Spectrometer three or five third-octaves ahead of the test frequency, respectively the second and the third harmonics are measured and automatically plotted as a function of the test frequency.

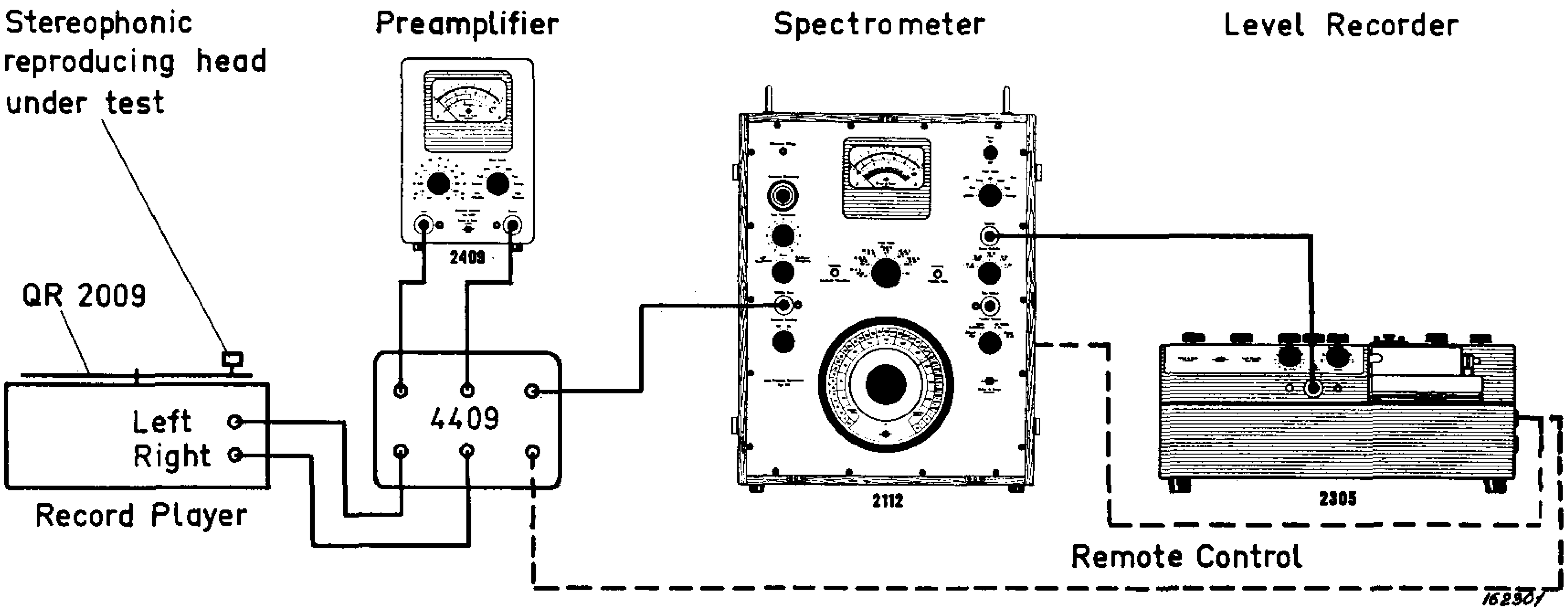


Fig. 16. Measuring arrangement for complete stereophonic pick-up test. The preamplifier should be able to power the synchro-starter which requires 100 mV across 10 kΩ.

Experimental Results.

In practical measurements, the switching dips are easily recognized and since their position is known beforehand, (the black dashes on the upper

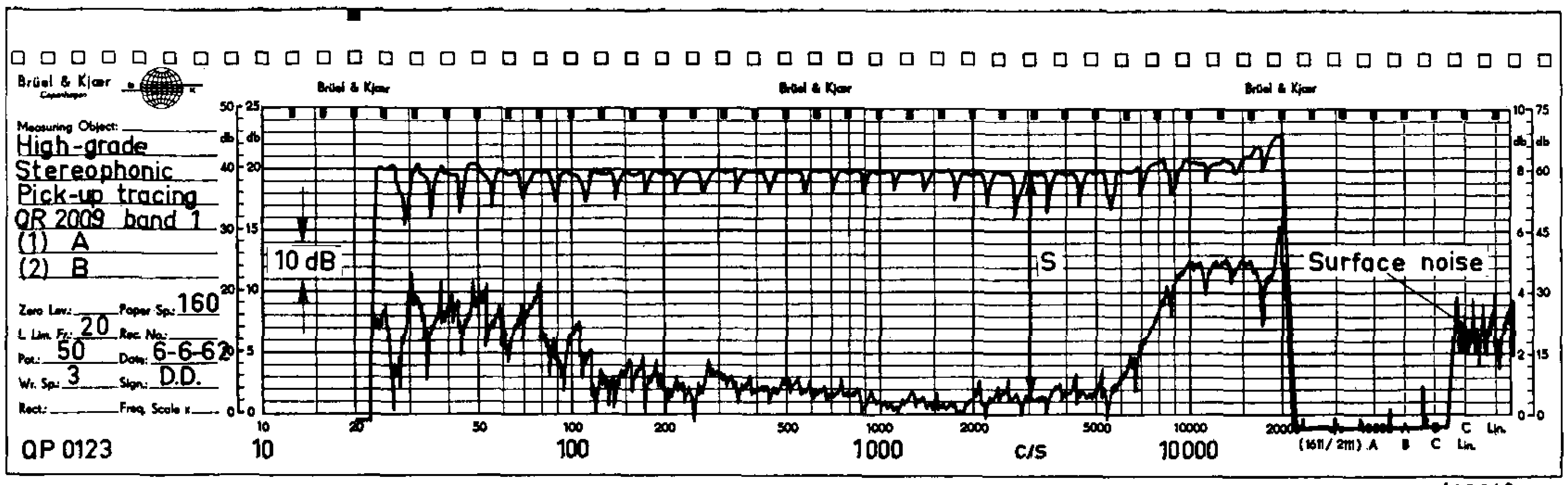


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Fig. 17. Successive plot on the same chart of the left and right output of a high grade pick-up tracing the QR 2009 band 1, carried out through the synchronous filtering arrangement. The separation is read directly in dB as the level difference. The influence of the synchronous filtering is clearly seen since the pick-up response is practically linear up to 7 kc/s.

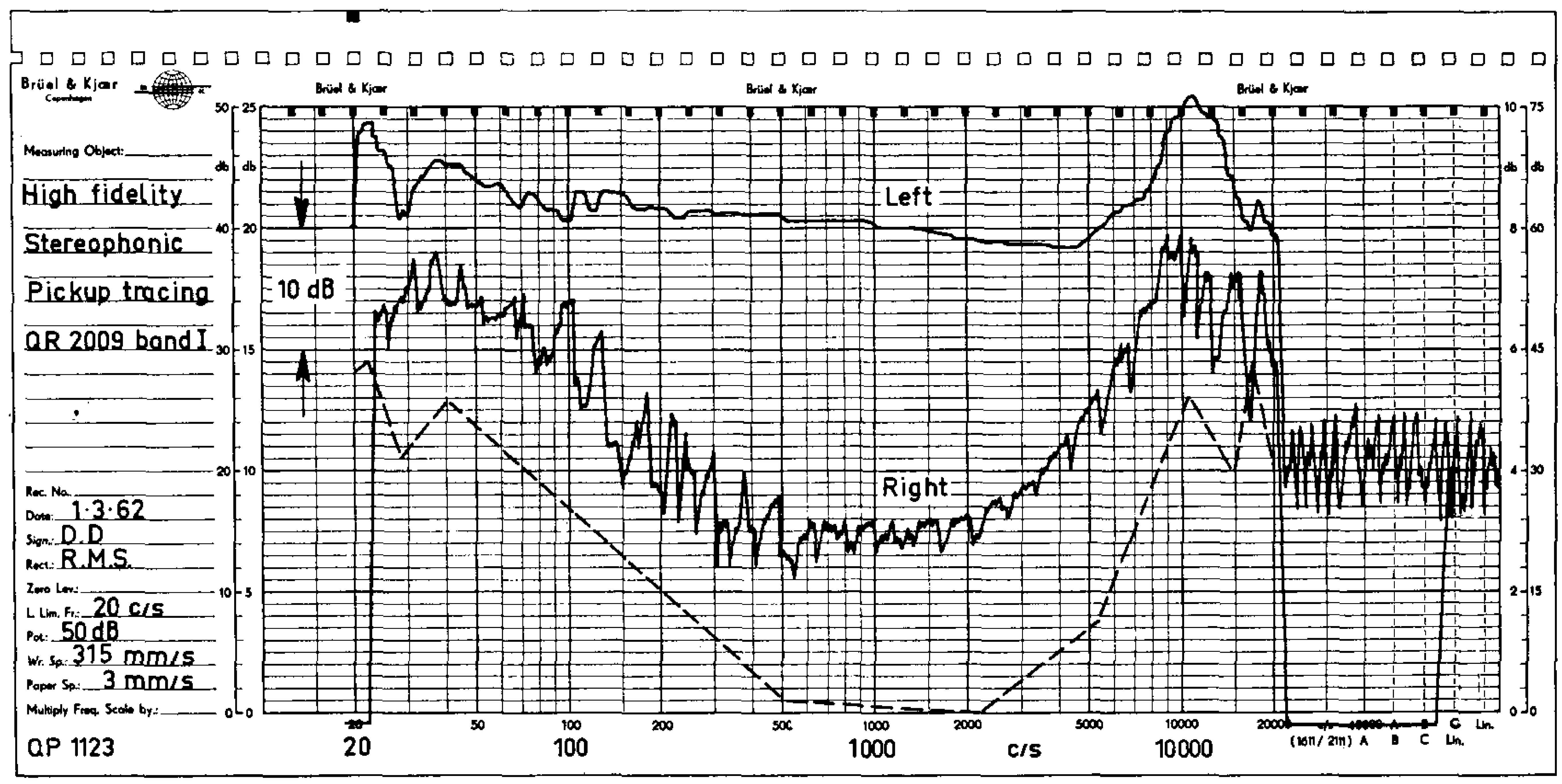

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Fig. 18. Check of the separation between channel of a "High Fidelity" stereophonic pick-up of the variable reluctance type. The separation is only higher than 20 dB from 250 to 3ooo c/s. The frequency response has been taken without filtering in order to detect all the irregularities of the pick-up itself.

scale of the recording paper indicate the filter center frequencies), they are easily taken into account if necessary in the final evaluation of the results. An illustration is shown in Fig. 17, where the cross-talk from the other channel is plotted directly below the frequency response. It should be noted that the characteristics of Fig. 17 are obtained with a pick-up of especially high quality in order to represent more the imperfection of the measuring set-up rather than of the pick-up itself. In practice, one is mostly interested in checking that the cross-talk lies below a certain number of dB under the modulation level and the filter switching dips have no significance. The frequency response may thus be taken without synchronous filtering as shown in the practical example of Fig. 18. While the cross-talk obtained in the case of Fig. 17 was partly due to the test-record itself, the cross-talk in the case of Fig. 18 is far above the cross-talk tolerance of the record. This is verified by means of the chart of Fig. 9 modified according to the pick-up's actual sensitivity (dotted line on Fig. 18).

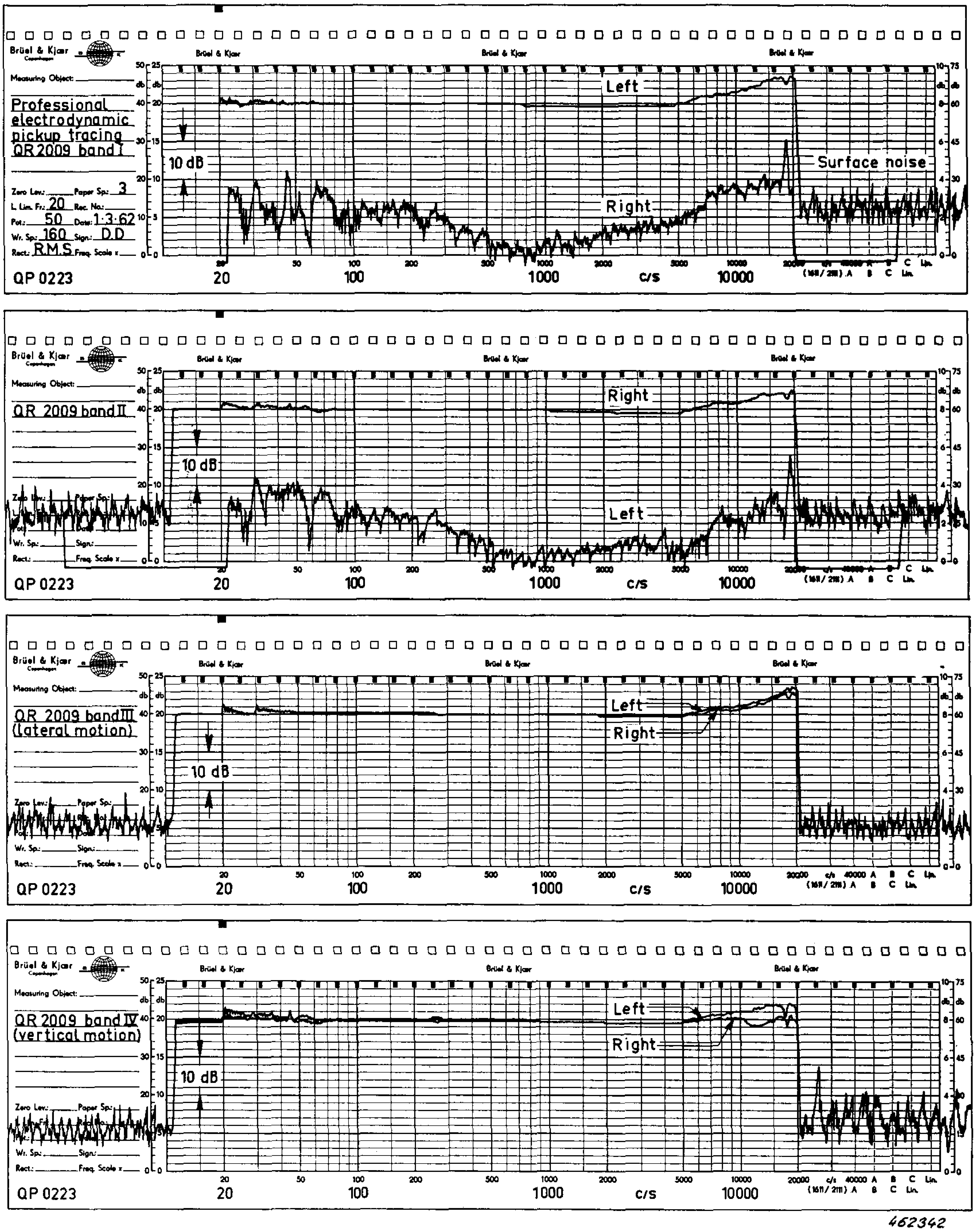

Fig. 19. Complete four-chart plot corresponding to the four directions of modulation available on the QR 2009 obtained with the set-up of Fig. 16.

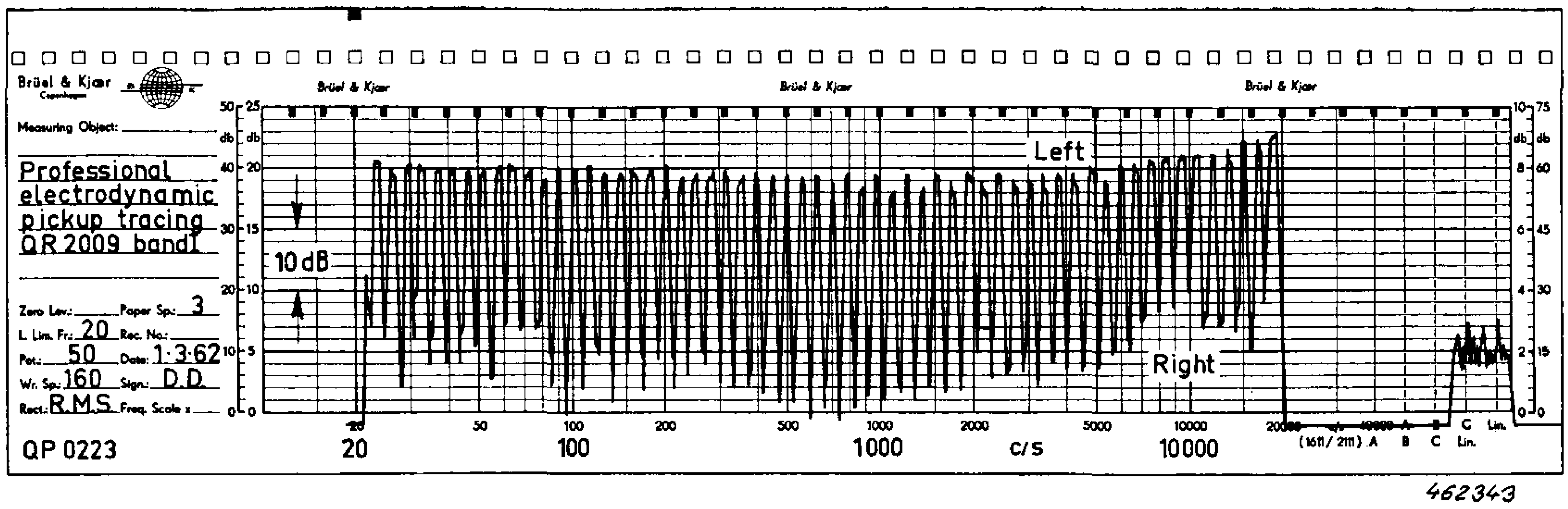

Fig. 20. Automatic separation measurements obtained with the two-channel selector of the Unit Type 4409. The tested pick-up and the set-up are the same as in the case of Fig. 17. After this first chart, the set-up continues the plotting of the three other charts without any intervention.

The complete stereophonic pick-up test including the four characteristics (A, B, A + B and A — B) for each channel can be executed more or less automatically. In the example of Fig. 19, corresponding to the same type of high grade pick-up as in Fig. 17, the four left channel charts were first plotted and then the recording paper was shifted back to the starting point in order to superpose the plot of the four right channel charts. Synchronous filtering was only switched in for cross-talk measurements below the wide band surface noise level. This method gives clear experimental results at the expense of a certain amount of manipulation between charts. This can be done however without lifting the pick-up which is continuously tracing the four bands.

A completely automatic procedure can also be obtained by using the two-channel selector of the Unit Type 4409 and letting the synchronous filtering operate through all measurements. The tracing of the first band (A) then appears as shown on Fig. 20. The information obtained is less detailed but still covers practically continuously the whole frequency range.

The automatic plotting of the four fundamental characteristics for both channels (8 curves) takes in these conditions 5 minutes, which is a very short time considering the amount of information obtained. In addition, the only manual work to be done is putting the pick-up on the record. The paper drive of the Level Recorder automatically stops when a complete plotting is carried out. This means the possibility for the operator to readjust previously checked pick-ups during that time, or eventually to control several measuring set-ups at one time.

Appendix A

Estimation of Play-back Losses on the Gliding Frequency Records.

As mentioned in the generalities on reference test records, the compliance of the record material plays a non-negligible role in the pick-up response at high acceleration levels (high frequencies) and small groove speeds. Generally this results in a small loss in response when playing the inner bands as compared with the response obtained on the outer bands. As described in the following some experiments carried out with high grade pick-ups (Ortofon type SPU-G with effective stylus mass 1—2 mg) have shown relatively close agreement between the losses predicted by the theory presented by F. V. HUNT at the 1st ICA[5], and the losses observed in practice.

According to this theory, the first order effects of elastic deformation may be resolved in two parts, i.e. the groove/pick-up response (H) and the translation loss (G).

The groove/pick-up response is governed by the stylus/groove resonance frequency (ω_o) and the damping factor of this resonance (d):

$$H = \left[\left(1 - \frac{\omega^2}{\omega_o^2} \right)^2 + d^2 \frac{\omega^2}{\omega_o^2} \right]^{-1/2} \qquad (1)$$

ω_o is a function of the mechanical constants involved: elasticity modulus (E) and Poisson's ratio (v) of the record material, stylus tip radius (R), downward application force (F_z) and effective mass (m) at ω_o of the stylus system referred to the point of contact:

$$\omega_o = 1.27\,(m)^{-1/2} \left((F_z\,R) \right)^{1/6} \left(\frac{E}{1 - v^2} \right)^{1/3} \qquad (2)$$

d, which is the inverse of the Q-factor of the resonance, is dependent both on the record material and on the tested pick-up. Measurements made in the frequency range 100 c/s — 2500 c/s by means of the Complex Modulus Apparatus Type 3930 show that the internal damping factor of the record material for bending waves is relatively small (o.03) and practically independent of the frequency (Fig. A 1). Longitudinal damping may be expected to be even smaller as is normal for plastic materials.

The translation loss function consists mainly in a sharp cut-off occuring at a frequency f_c dependent on the groove speed u:

$$G = 1 - \left(\frac{f_c}{f} \right)^2, \text{ with } f_c = \frac{3.33}{2\pi}\, u \left(\frac{E}{RF_z\,(1 - v^2)} \right)^{1/3} \qquad (3)$$

(expression valid "under conditions for which moderate tracing distortion

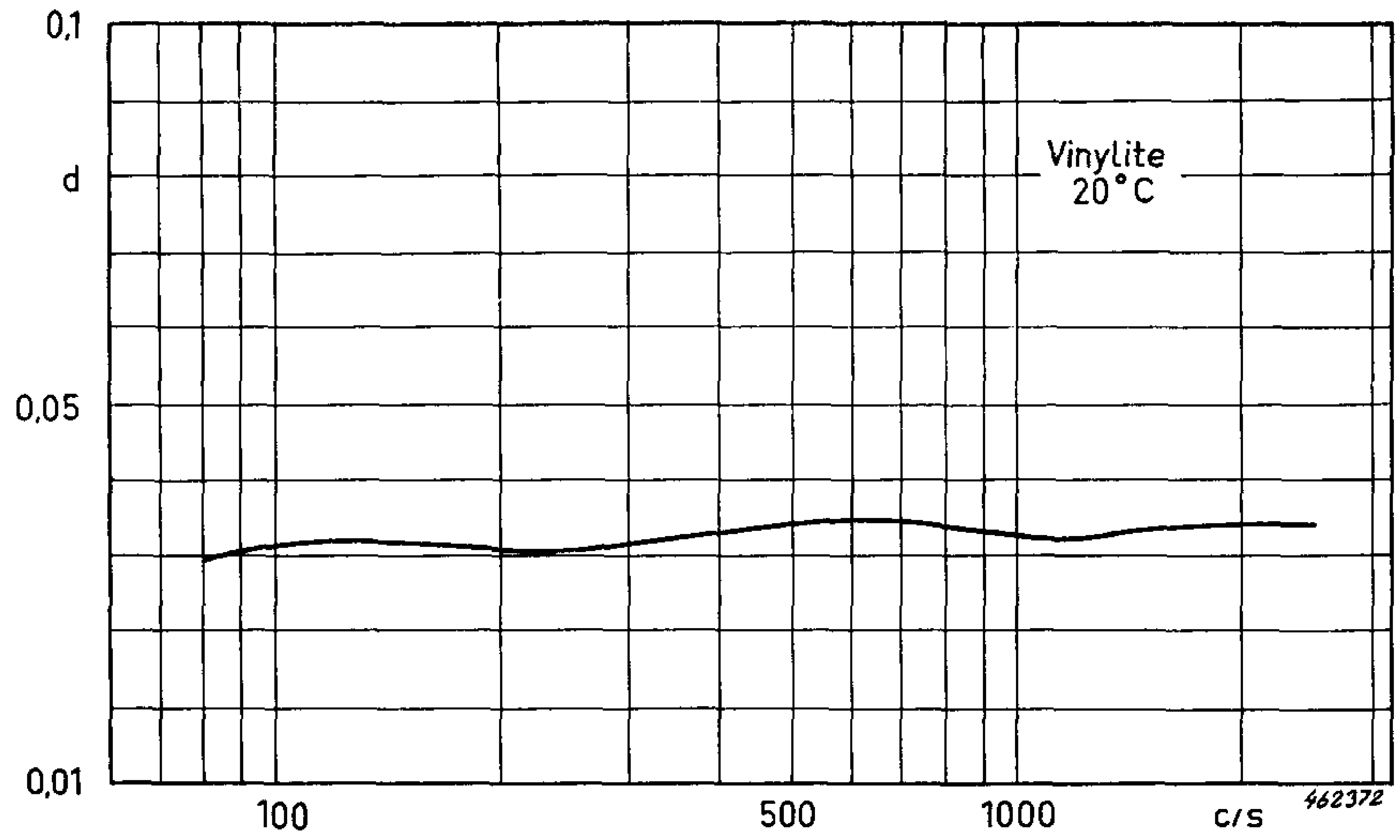

Fig. A 1. Intrinsic damping of the record material measured by the bending wave method.

would be predicted by the rigid-wall theory"[4]). The nomogram of Fig. A 2 in which the known parameters have been numerically included ($E = 3 \times 10^9$ N/m^2, $v = 0.35$, rotation speeds of 33 and 45 rpm) enables the calculation of G to be readily made graphically.

Since only G depends on the groove speed (u), the deviation in response between bands is given by (3). The expression is the same in lateral, vertical or monochannel modulation.

The agreement betwen theory and practice is illustrated by the results obtained on the QR 2007 test record providing ten different groove speeds (or band diameters). A preliminary condition for the measurement is that the recorded level varies as little as possible from one band to another. From Fig. A 3, showing superposed plots of the velocity level in the different bands of the QR 2007 (nickel mother-matrice), it is seen that this condition is well satisfied up to around 10 kc/s. Measurements are also possible at 15 kc/s where the translation losses are substantially higher, though the error between bands is larger.

In order to minimize the influence of the residual differences in level of the recordings, the following procedure utilizing the set of curves in Fig. A 4 is used:

(a) The relative level measured when reproducing the different bands is marked on transparent paper with respect to the represented axis of coordinates.

(b) The pattern is moved in the vertical axis direction until the best possible coincidence is obtained between the 10 points and one curve (or intermediate) of the set.

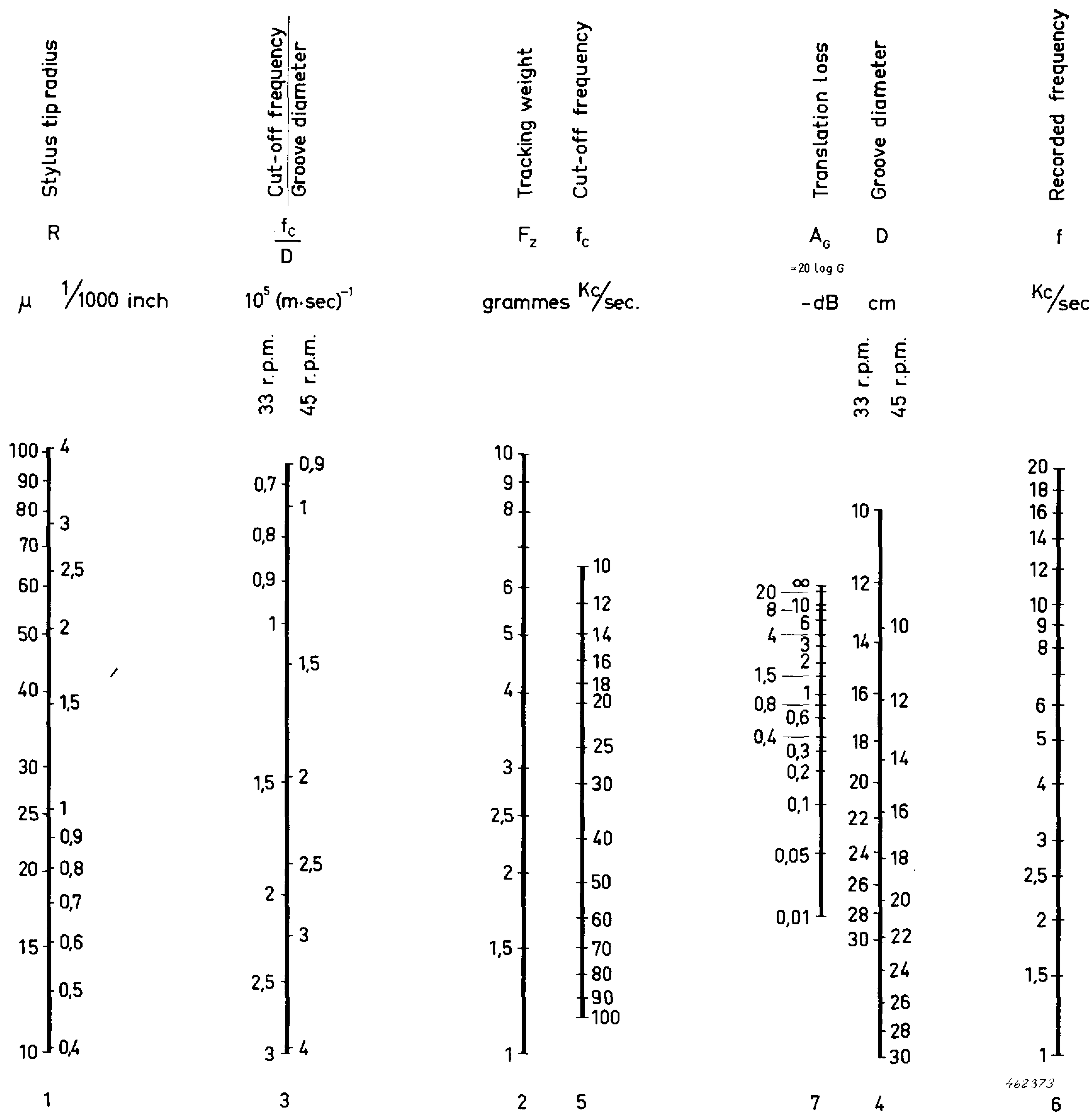

Fig. A 2. Nomogram for determination of the translation loss on vinyl records. (Equation (3) with $E = 3.10^9\ N/m^2$, $v = o.35$).

Example of application at 45 rpm:

$R = 17\ \mu$, $F_z = 3.5$ gr	→	$f_c/D = 2.2\ 10^5 (ms)^{-1}$
$f_c/D = 2.2$, $D = 12.4$ cm	→	$f_c = 27$ kc/s
$f_c = 27$ kc/s, $f = 15$ kc/s	→	$A_G = -3$ dB $(G = o.7)$

A value of RF_z of about 60 is read both at 10 kc/s and 15 kc/s. The stylus tip radius of the pick-up used (Ortofon SPU-G) was 17 μ and the downward application force was adjusted to 3.5 grammes, the product of which is 60. The suitability of the expression (3) for practical estimation of the translation loss is thus demonstrated but the precision will be generally insufficient to allow a determination of the stylus tip radius or of the downward application force to be made by this method.

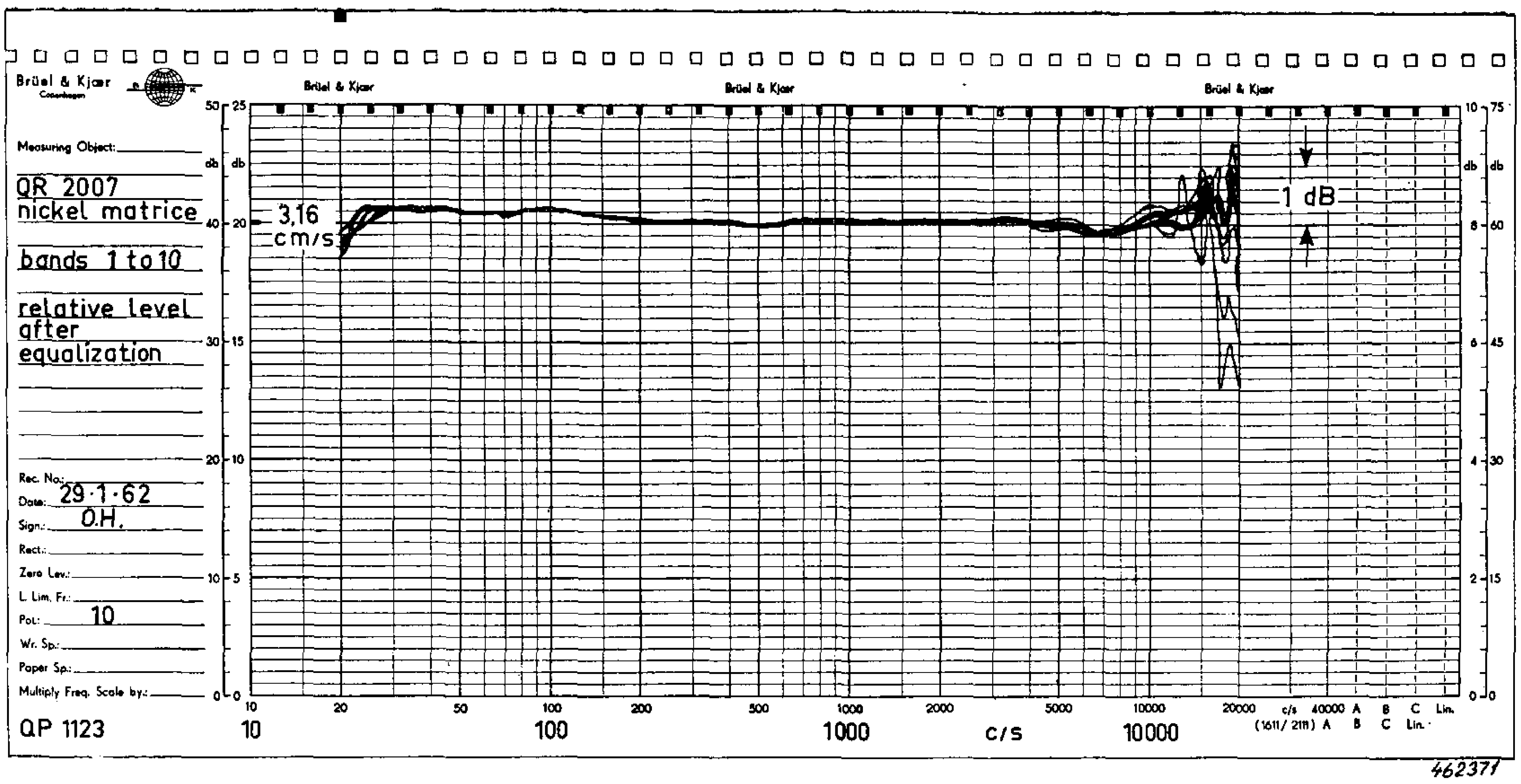

Fig. A 3. Superposed plot of the recorded level in the different bands of the record type QR 2007 with "Linear" equalization. Compare with Fig. 9.

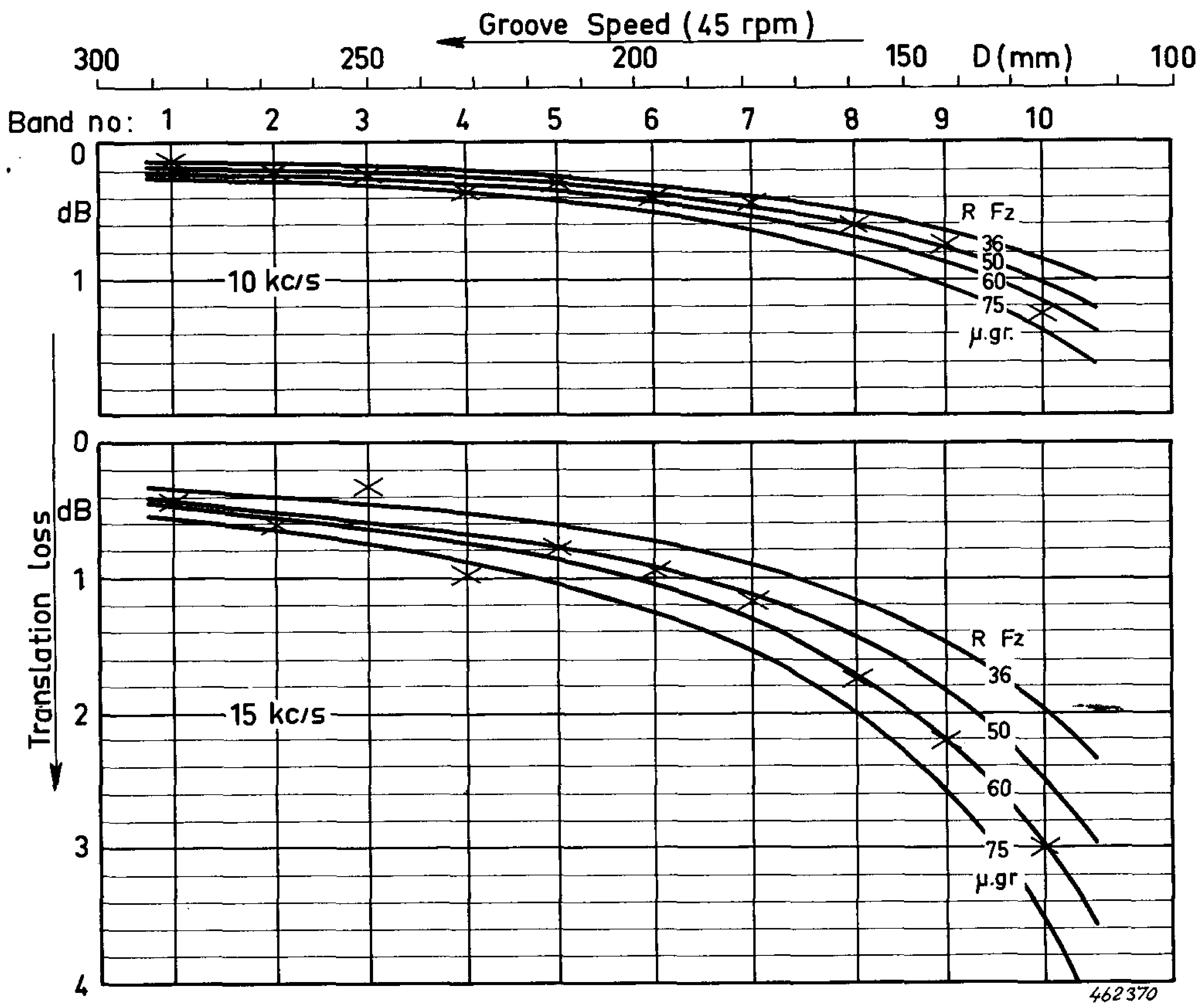

Fig. A 4. Theoretically calculated translation loss at 10 kc/s and 15 kc/s as a function of the groove speed (diameter at 10 — 15 kc/s) for different values of the product $R\ F_z$.
×××: measured losses for a pick-up having a tip radius of 17 μ with an application force of 3.5 g ($RF_z = 60$).

Appendix B

Some Remarks about the Cutting of the B & K Gliding Frequency Records.

By Civil-Eng. *Lindskov-Hansen,* A/S Ortofon, Trommesalen 5, Copenhagen

Principle of the disk recorder (Ortofon Stereo-cutter Head Type DSS 601). Figure B1. shows the principle of the electrodynamic cutting head of the Ortofon equipment used in the production of the B & K Test Records. The cutting stylus C is fastened to a dynamically balanced bridge, which is

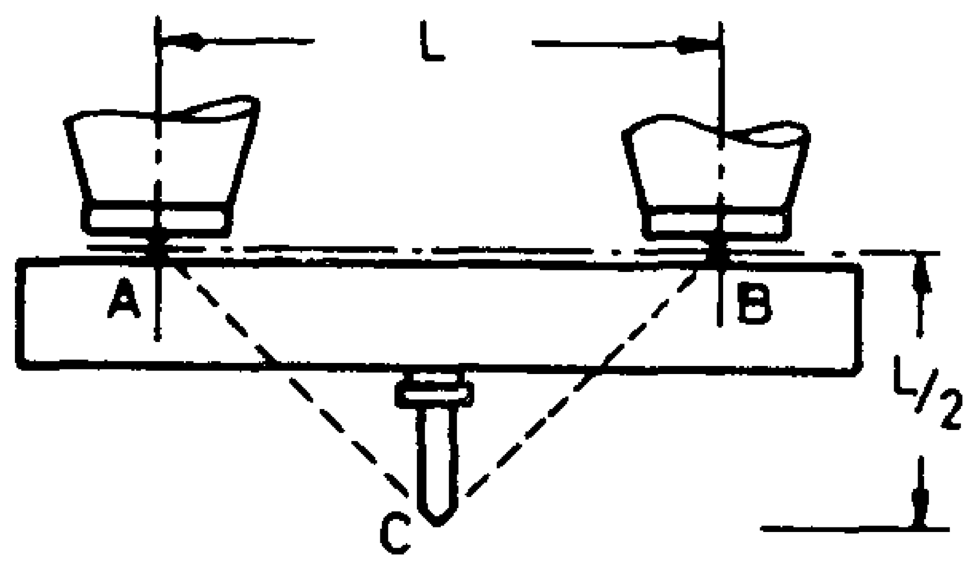

Fig. B1. Sketch of the moving system of the Ortofon stereo-cutter head.

attacked in A and B by the stereophonic driving coils. The balance is achieved in such a way that the system moves around point B under the action of a force applied in A and reciprocally. The cutting stylus being located in such a way that the angles ABC and BAC are 45°, its movement around A or B is obtained when only one coil is excited. With the small displacement involved, a true 45°/45° modulation is thus achieved. Lateral modulation is obtained when the attacking forces are equal and in anti-phase and vertical modulation corresponds to equal movements of A and B. The two driving coils are suspended separately by leaf springs to the frame so that each can vibrate independently in the vertical direction. They are

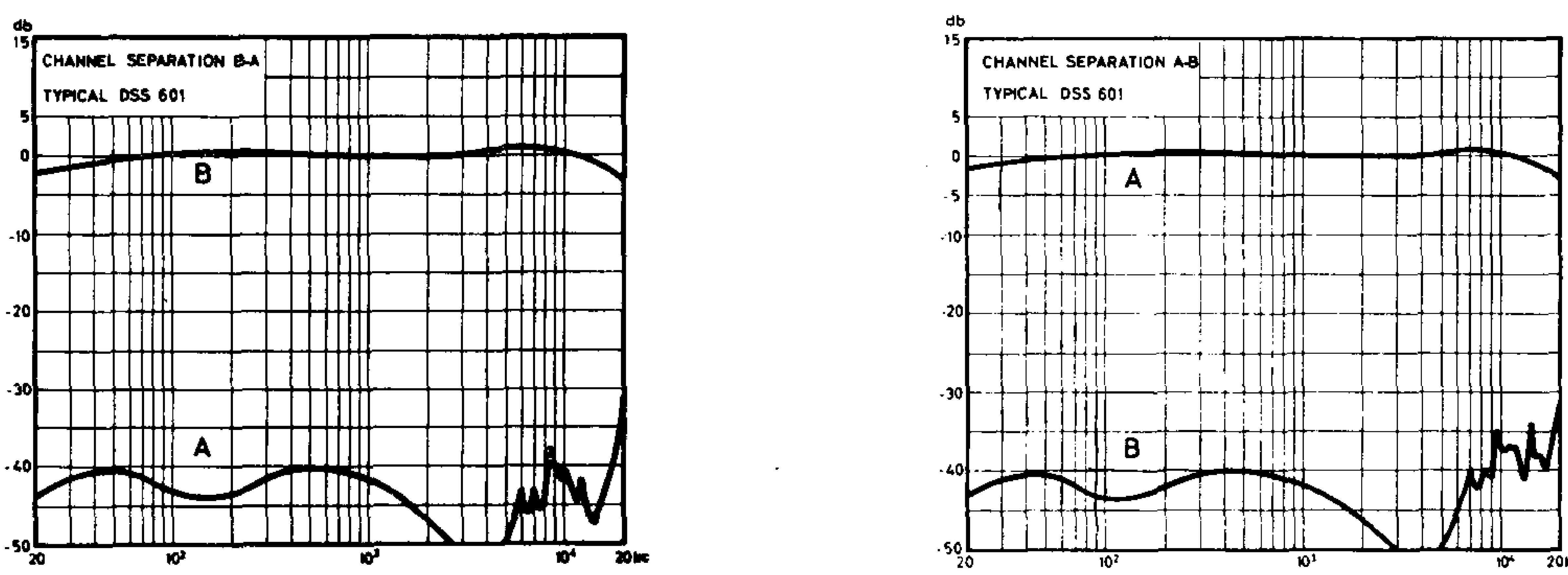

Fig. B2. Channel separation of the disk recorder

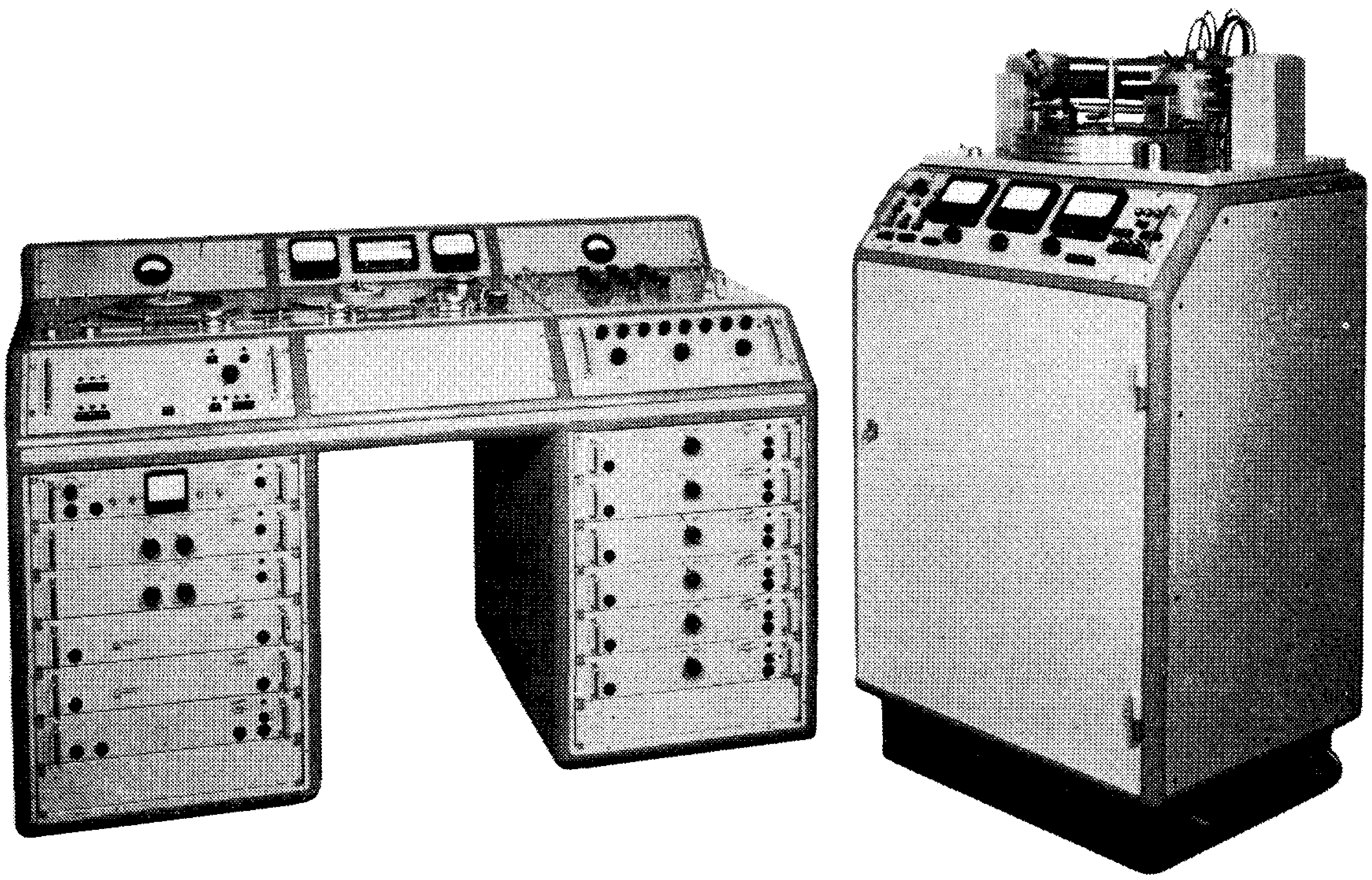

Fig. B3. The Ortofon disk recording equipment. The square shaped cutter head is seen to the right, suspended over the turn-table.

connected to the bridge through leaf springs which transmit the vertical movements completely, but allow rotational movement of the bridge relatively to the coil armatures.

In this way, the following features are achieved:

1. well-defined points of attack of the vertical driving forces on the bridge.
2. mechanical decoupling of the driving armatures from the bridge and from each other as far as rotational movement is concerned.
3. the bridge is hanging in the coil armatures and has no other suspension to the frame. Thus the bridge has been relieved of any load other than the mass of the stylus and of the bridge itself. It can therefore be made very light.

The cross-talk of the head is quite satisfactory as shown on Fig. B2. A general view of the equipment is given in Fig. B3.

Special features employed.

The recorder is feed-back controlled and normally presents a frequency linearity of ± 1 dB. For the recording of the Gliding Frequency Records which is obtained from a B & K Beat Frequency Oscillator Type 1014, use is made of the regulating "compressor" of the latter. This giving an additional regulation factor of about 30, a perfectly flat frequency response of the recorder is ensured. In order to obtain correct regulation of both channels from the unique compressor circuit, overall differences in response where measured and corrected by appropriate filters until a deviation of less than 0.2 dB between channels was achieved.

The further difficulties encountered in satisfying the frequency linearity tolerances of the QR 2009/2007 were the following:

1. a dip of about ± 1 dB appeared in the recording around 13 kc/s, which was caused by a mechanical resonance in the cutting head.
2. at very low frequencies, a small part of the vertical component of the modulation may be transmitted to the whole recorder. This spurious modulation is recorded vertically (i.e. on both groove walls) and since it does not affect the feed-back coil, it causes a deviation in frequency response (in bands A, B, A-B) and an increase in cross-talk (for bands A and B).
3. the record material does not keep exactly the shape it has been given by the passage of the cutting stylus.

These difficulties have been overcome in the following way:

1. by using a rotation speed of 33⅓ rpm at recording instead of the nominal 45 rpm, the spurious resonance dip is transferred to around 18 kc/s at reproduction. Using a lower rotation speed in order to reject the resonance beyond 20 kc/s was not feasible because of the sensitivity to vertical modulation of the recorder at the low end of the frequency range.
2. as a result of using a reduced recording speed of 33⅓ rpm, it was necessary to increase the mass of the cutting system up to twice the normal mass in order to maintain the separation between channels at higher than 20 dB for the lowest frequencies. The related deviation in frequency response was corrected by a suitable filter in the feedback circuit.
3. the deviation in frequency characteristics caused by the "cutting distortion" mentioned in § 3 has also been compensated by correcting filters. This deviation was determined by accurate investigation of a nickel mothermatrix of a recording made without correction.

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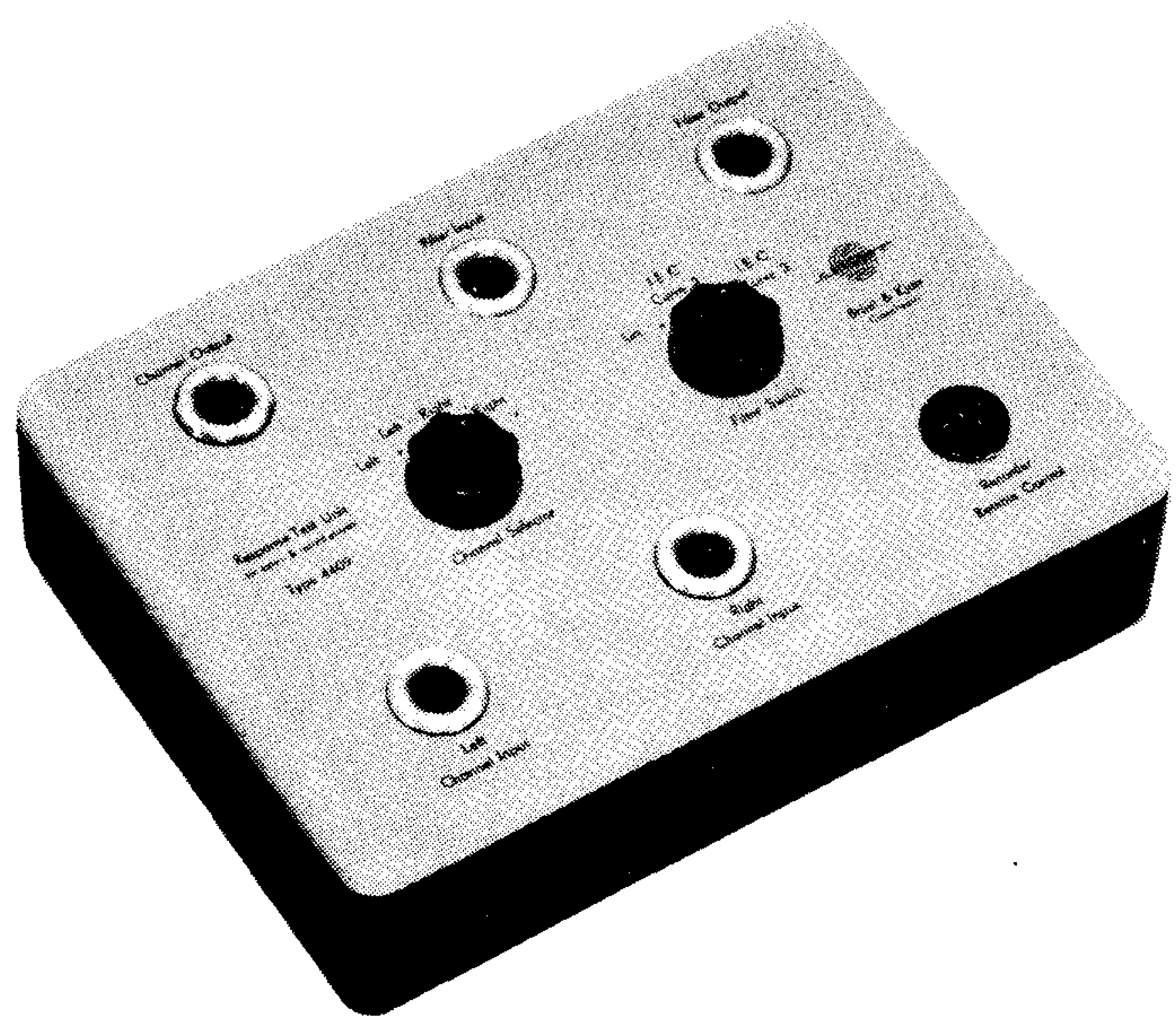
News from the Factory

Response Test Unit for Tape- and Record Players Type 4409.

The response Test Unit Type 4409 forms the link between the B & K automatic frequency response plotting instruments and the reference recordings used for testing sound reproducing equipment. Where the recorder is integrated with the reproducer as in the case of tape recorders, motion



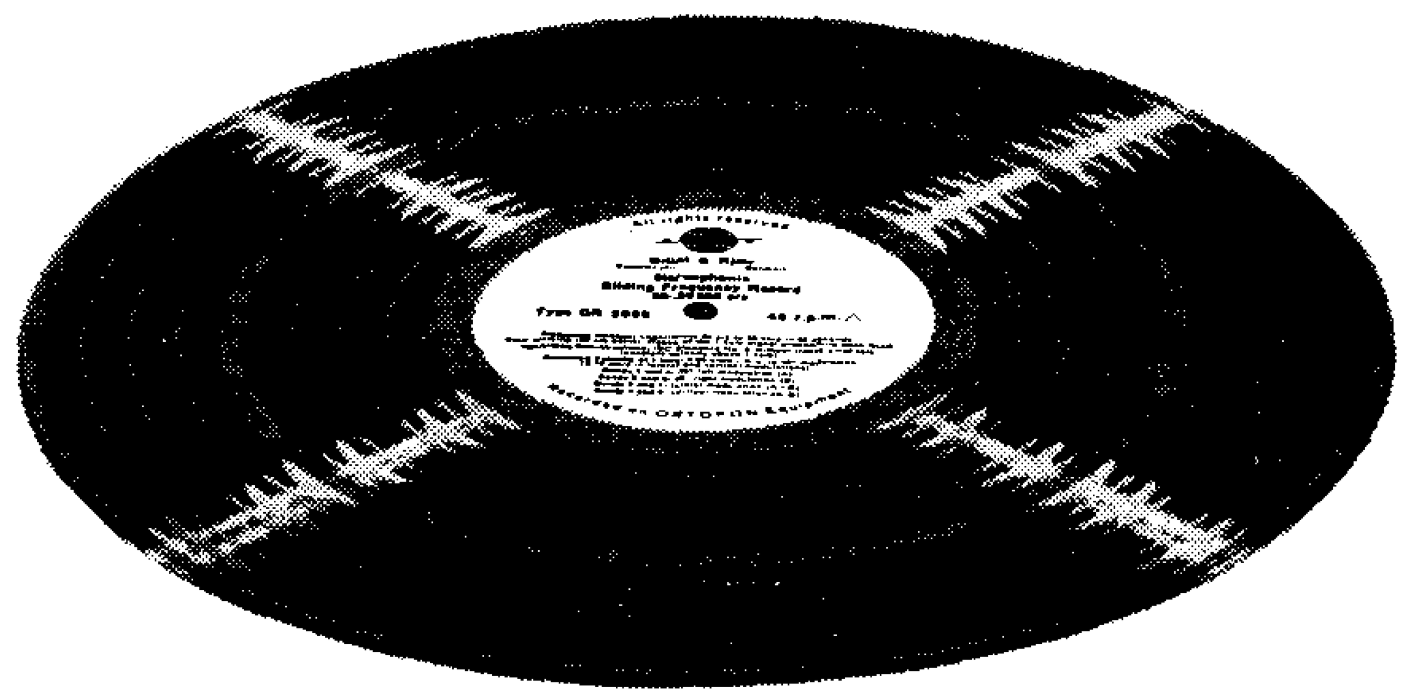
picture systems etc., reference recordings are taken from the constant voltage output of a B.F.O. and in the case of phonograph testing, precision reference disk recordings are used as described in this issue.

The Unit groups three different functions:

1. a synchro-starter operating automatically the paper drive of the Level Recorder Type 2305 under the action of a 1 kc/s signal.
2. a two-channel selector for use in testing stereophonic equipment.
3. equalizing filters for correcting the characteristics of the gliding frequency records according to the different standards in use.

Monophonic Gliding Frequency Recordings Type QR 2007.
Stereophonic Gliding Frequency Recordings Type QR 2009.

These recordings are made on vinylite and delivered as boxes containing 5 records. The two sides of each record being identical, a total of ten sides are available—a large enough quantity to guarantee a great number of playings without alteration of the characteristics. This number, however, is greatly dependent on the care exercised in the use of the records. By conserving one side as a reference, it is possible to check on the service life of each record in use.



On each side is recorded a succession of logarithmic frequency sweeps 20 c/s—20 kc/s. Each sweep is preceeded by a 1 kc/s reference and starting signal. The different sweeps present different groove speeds owing to the differences in diameter (i.e. different wavelengths).
Ten lateral cut sweeps are available on the QR 2007, while the QR 2009 presents two groups of four bands, each group containing

1. left modulation (A)
2. right modulation (B)
3. lateral modulation (A + B)
4. vertical modulation (A — B)

The two first bands of each part of the records QR 2009 allow cross-talk measurements to be made down to —40 dB in the middle of the audible range (from 500 c/s to 2ooo c/s).
The cutting process and the dimensions are in accordance with the Recommendations of the International Electrotechnical Commission (IEC 98 and 98-1) recognized by most countries. The rotation speed is 45 rpm.

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