Gramophone Turntable Speeds

What is the Best Speed for Microgroove Recording?

By G. F. DUTTON,* Ph.D., D.I.C., A.M.I.E.E.

THE history of the disc gramophone shows that there has been a great variety of turntable speeds and of groove dimensions. The early discs were of about 7in to 8in in diameter and it will be shown later that the turntable speed of about 78 r.p.m. was justified at that time. The groove dimensions and amplitude of cut were dictated by the need for direct mechanical reproduction through a horn system. The development of the more delicate electrical pickup mechanisms has naturally changed these requirements, but mechanical gramophones are still used by many people throughout the world. A very important aspect of the gramophone record was its universality. Except for slight variations of frequency characteristics a record made in this country could be played wherever there was a pickup or a portable gramophone. The introduction into the commercial market of the microgroove and at least two alternative speeds robs the disc of its universal application.

It has been stated on good authority that of the sales of the standard 78-r.p.m. records throughout the world, 40 to 50 per cent go to customers who have the portable mechanical type of machine only. It is also interesting to note that though the number of portable mechanical gramophones exported from this country greatly exceeds the home consumption, the latter has shown a distinct rise since the end of the war. The U.S.A., being a highly electrified country, has no mechanical gramophone problem. It is to be expected, therefore, that a firm in the U.S.A. can embark on new standards of speed and groove dimensions with less embarrassment than firms in this country.

It must be clear, therefore, that whatever alternative speeds and groove dimensions are eventually adopted, the standard 78-r.p.m. record must continue for a considerable time.

The playing of a gramophone record is a very personal form of entertainment; one has the choice of a number of artists performing any one work and one can play it when one likes. Perhaps the mention of the broadcast programme called "Desert Island Discs" will illustrate the personal choice of a variety of short items together with the portable gramophone angle. I presume that the desert island is not electrified.

We should perhaps at this stage state the specification for the performance of a gramophone disc. There is no doubt, however, that it will be the public who will finally choose the specification, but we may usefully list what we think to be the items which could be discussed here on technical grounds. Before we do that we should bear in mind that the buying public can, I suggest, be roughly divided into two age groups —14 to 30 and 50 to 70. The first group, 14 to 30, is the romantic group, requiring dance music, hot jazz, crooning, etc., with a fair demand for the more serious classical music. They have little money to spend and probably prefer to spend only a little at a time. The second age group, 50 to 70, is the connoisseur group with more money to spend and more time to listen to long operatic works. One age group would tend to sway the gramophone industry to concentrate on short five-minute records and the other to adopt long-playing records. The use of long-playing records to string together whole series of dance tunes would, I think, be ridiculous. It is difficult enough, with the 10-in, 78-r.p.m. record, to choose suitable coupling items for the two sides of the disc. I must also mention that there are many lengthy classical works covering, say, a dozen 12-in discs, and the sales of one or two discs from the series far exceeds the sale of the complete work.

Record Materials

It would seem, therefore, that the record of short duration, say up to five minutes, is a definite requirement. Does the standard 78-r.p.m. record fulfil the requirements of a short-duration record? To a large extent it certainly does, but we must consider whether the size of the record player, the storage of records, the economical use of low surface noise and high-grade plastic moulding material are items which would swing the development towards small diameter lower-speed discs. Shellac is an ideal resin for moulding, since it flows freely at a moderate moulding temperature and pressure. Its great drawback is its dimensional instability without the use of a large percentage of mineral filler. This filler is the cause of most of the so-called surface noise. The record, however, stands up well to the variable treatment that it may experience by reason of the great variety of needles and pickup playing pressures used throughout the world.

The unfilled vinyl co-polymer resins can only be used with safety by the modern lightweight pickup with precision needle points. The plastic is expensive, and, like most high molecular weight resins, requires high moulding temperatures and pressures. This in its turn is liable to cause strain which may lead to warping. When using vinyl plastic, therefore, the small disc is to be preferred.

Can long playing be fulfilled by the 78-r.p.m. standard disc? History shows that there have been many attempts and some quite successful. For instance, the World Record Company in 1910 brought out a disc claiming to play from 10 to 100 minutes employing a constant groove speed. A sample record is extant which plays for 12 minutes, the turntable speed varying from 30 r.p.m. on the outside to 80 r.p.m. on the inside. The use of constant groove speed is the most

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efficient way of operating a disc, since the quality can be kept constant at a predetermined value. The mechanism to produce this constant groove speed and at the same time avoid "wow" and "flutter" is something of a mechanical problem.

The 33⅓ r.p.m. speed was introduced for 16in discs to be used in conjunction with films. With these large-diameter discs 33⅓ r.p.m. is justified. In recent years it has been used by broadcasting concerns both for processed transcription records and for lacquer recordings. The groove dimensions are the same as for 78-r.p.m. standard. The 16in disc is, of course, too large for domestic use. If we examine Fig. 1 we see a family of curves showing the relation between playing time and disc speed for various overall diameters. The minimum groove speed is 16in/sec and there are 100 grooves per inch.

The playing time of a record is determined by the width of the recorded area on the record, the spacing between individual grooves, and the angular speed of the turntable. The average groove spacing depends very largely on groove width, which in turn is controlled by the size of the needle point, and to a slightly lesser degree on the amplitude of the recording cut. The turntable speed and the total width of recording allowed are related together by considerations which involve the overall diameter of the record and the least permissible tangential groove speed; the latter depends in turn on the same two quantities, that is to say the needle size and the amplitude of cut, which are involved in groove spacing. Since these two features control playing time in two distinct ways, they merit the first consideration.

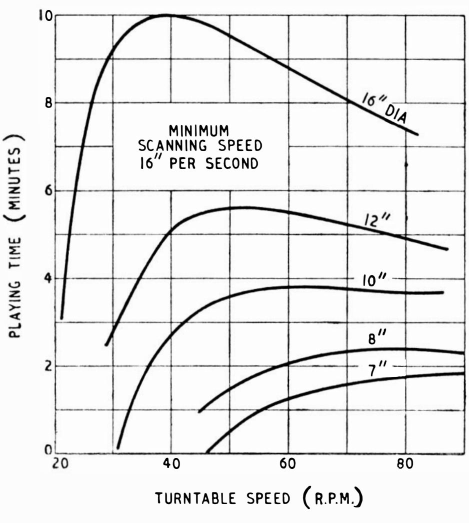
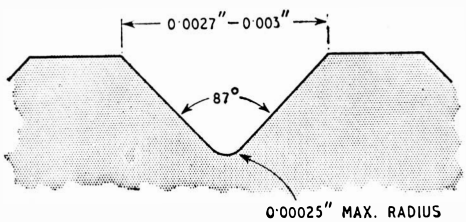


Fig. 1. For a given minimum groove speed there is an optimum turntable speed for maximum playing time with any given outside diameter of record.

Fig. 2. Principal groove dimensions in microgroove recording.



For use on microgroove records, the radius of the hemispherical tip of the needle has been reduced from the value of 0.0025in, associated with standard records, to 0.001in. To avoid excessive wear or major damage to either the needle or the record, it has been necessary to reduce the needle pressure and stiffness by at least the square of this ratio. This has been achieved partly by reducing the mass of the pickup head, and partly by some degree of counterbalancing: further reduction of needle pressure would almost inevitably have to be achieved by increased counterbalancing alone.

If the radius of the needle point were reduced below the new figure of 0.001in,

(a) the uniformity of performance between needles would deteriorate seriously,

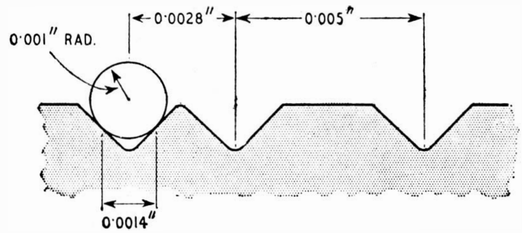
(b) the needle tip would be too susceptible to accidental damage,

(c) the counterbalancing would become critical and would involve individual adjustment, and

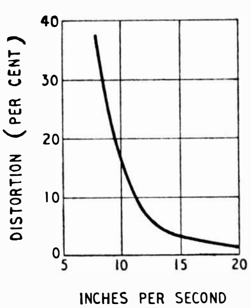
(d) the ratio of the residual moment to the moment of inertia would be so low that the needle might fail to maintain proper contact with records which are slightly warped.

In all proposed microgroove records, the amplitude of the lateral cut has been reduced in, at least, the ratio of the needle-tip reduction, at the lower frequencies, which determine the greatest amplitude. Further decrease would not give a proportionate increase in playing time, particularly if the groove pitch is made variable. On the other hand, with pre-emphasis the amplitude of cut at high frequencies is only slightly below the standard (78 r.p.m.) records.

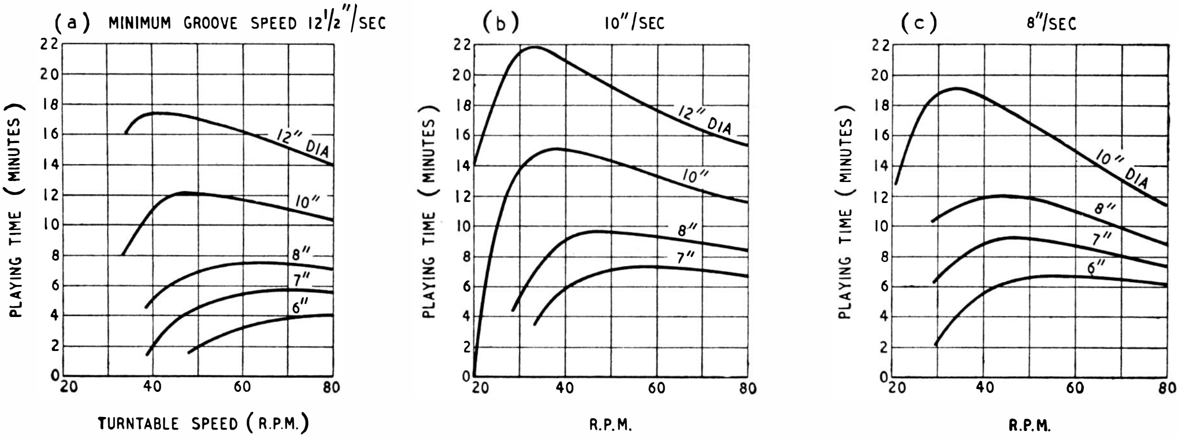
Fig. 2 shows the dimensions of cross-section of the groove. The best position for the needle to engage the groove wall is half-way up the wall where there is the least danger of distortion of the wall by rounding. It will be clear from Fig 3 that the width of the needle at the point of engagement is 0.0014in and that the absolute minimum groove spacing is, in consequence, 0.0028in. In extremely quiet passages, a record could theoretically be cut to 350 grooves to the



Above: Fig. 3. Using the groove of Fig. 2, the theoretical minimum spacing without modulation is 0.0028in (about 350 grooves per inch). In practice an average of 250 g.p.i. is rarely exceeded.

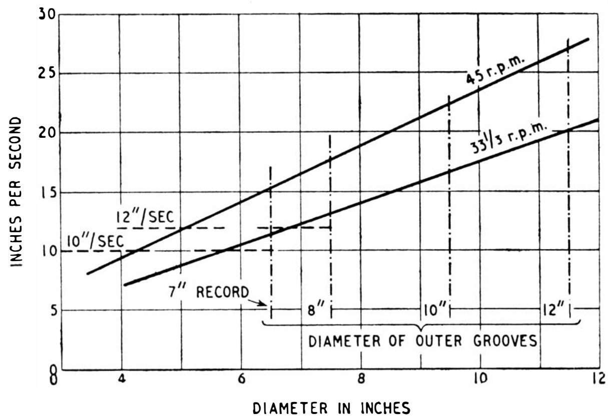


Left: Fig. 4. For a given stylus radius and lateral velocity of cut, distortion is inversely proportional to the fourth power of the tangential (linear) groove speed.



Above : Fig. 5. Playing time, for 250 grooves per inch, in terms of minimum groove speed, external diameter of disc and turntable speed.

Right : Fig. 6. Relationship between linear groove speed and groove diameter.



inch, but in practice an extra tolerance has to be allowed to ensure that grooves do not cut into one another. An allowance for this effect leads to a groove-to-groove minimum spacing of 0.0035in, and a maximum of 280 grooves per inch in silent and fairly quiet passages. Heavy recording will require an increase of spacing of at least 0.0015in, making 0.005in in all, but, as loud passages do not in general predominate, it is thought that a variable groove-pitch system would allow an average of 250 grooves per inch. All the following calculations of playing time are made on this assumption.

The distortions which arise in following a groove with a needle point of finite size have been analysed in detail by Pierce and Hunt[1], Lewis and Hunt[2], and others. Briefly, the expression for distortion contains terms of the form:

$$\frac{r^2 V^2}{S^4}$$

where r is the needle-tip radius, V is the lateral cut velocity, and S is the tangential velocity. This means that, in order to produce similar distortion conditions S^2 varies directly with rV.

In considering harmonic distortion of lower frequencies, or intermodulation between low and high frequencies, both r and V have been reduced by 2.5 to 1 from their values with standard records, and hence the minimum tangential speed may be reduced in the same ratio for the same amount of distortion. Harmonic distortion of high-frequency notes, or intermodulation between high notes, however, involve values of V which are unchanged from the standard record, and here a reduction of S in the ratio of the square root of 2.5, or only about 1.6, is justified. Taking into account the importance of the various types of distortion, it is probable that the permissible decrease of tangential velocity, from that of the standard record, is in the ratio of 2 to 1.

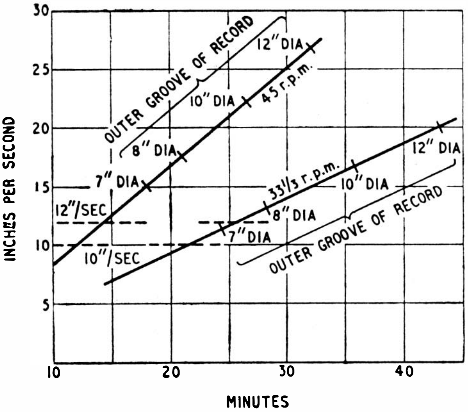
Existing standard 78-r.p.m. records in extreme cases play to a tangential velocity as low as 16 inches per second, and distortion is apparent at the inner grooves, if the amplitude of cut is high. In fact the quality in loud passages is not noticeably impaired at 22 inches per second. On this basis we should recommend that microgroove records should preferably be terminated at 12 inches per second, and certainly never allowed to play beyond 10 inches per second.

Experience has shown that the distortion which sets in at a certain point in the playing of the record, increases at a rate which appears to be out of all proportion to the change of radius. It cannot be too strongly emphasized that this is completely justified in theory by its dependence on the reciprocal of the fourth power of the speed. Similarly, we are quite justified in drawing a strong distinction between speeds differing as little as 12in and 10in per second, because this small difference accounts for more than a two-fold increase of distortion. This is illustrated in Fig. 4.

Playing Time

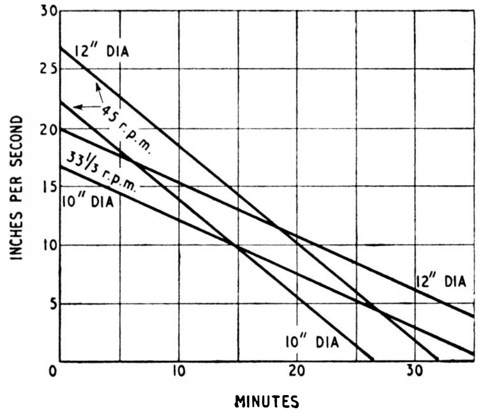
On the assumption of an average of 250 grooves per inch, the playing time can be calculated for various sizes of record, minimum groove velocities, and turntable speeds. From Fig. 5 it will be seen that for each record size and minimum groove velocity there is actually an optimum turntable speed; at this speed the outermost groove is played at twice the minimum groove velocity, and the music occupies just one half

[1] *J. Acous. Soc. Amer.* Vol. 10, July, 1938.
[2] *J. Acous. Soc. Amer.* Vol. 12, January, 1941.

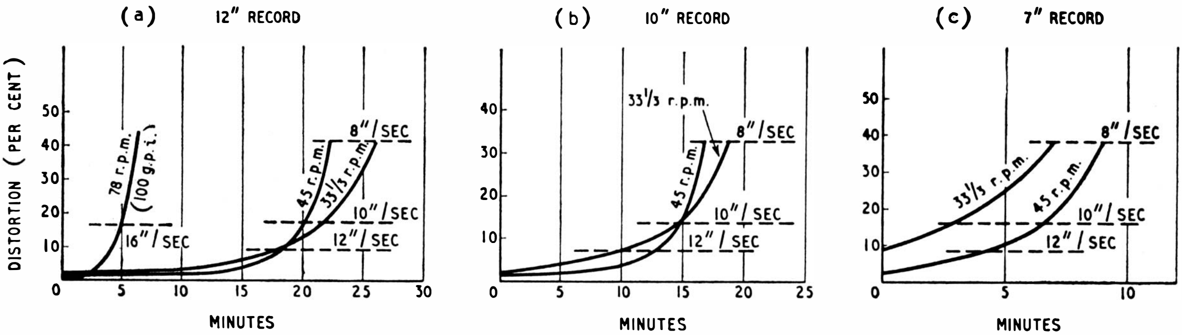


Left : Fig. 7. Groove speed as a function of time, with zero time at the centre of the record.

Right : Fig. 8. Data for 10in and 12in discs replotted from Fig. 7 with zero time at start of outer groove.



Below : Fig. 9. Limitation of playing time by distortion at the inside groove diameter for discs of 12in, 10in and 7in. external diameter at alternative turntable speeds.



of the radius of the record. The curve of playing time plotted against turntable speed is, however, very flat near its maximum and change of speed by 20 per cent in either direction from the optimum only results in reducing the playing time by 4 per cent from the maximum. For this reason, it is only necessary to consider the two figures of 33⅓ r.p.m. and 45 r.p.m. which have already been adopted: if the optimum for any given set of conditions falls centrally between these two, no great loss can arise from adopting either.

It is obvious that linear speed, which has a marked effect on quality, is greater at the starting groove of a record turning at 45 r.p.m. than on one of the same diameter turning at 33⅓ r.p.m., but equally clear that, as the needle moves into the centre more rapidly in the faster record, the linear speed falls off more rapidly. Actually, there is a time at which the two records, started at the same instant, will be moving at the same linear groove speed and, after this point, the record which is rotating at only 33⅓ r.p.m. will actually have the higher linear speed and therefore give the better quality. This critical point occurs at about 15 and 18 minutes from the start on 10in and 12in records respectively, and occurs at linear speeds of about 9½ and 11½ inches per second.

In Fig. 6, the variation of groove velocity is plotted against the diameter of the groove which is being played. The diameter of the inner groove is given by the intersection of the appropriate line with the limiting groove velocity chosen: from this the useful area of the record can be deduced. In Fig. 7, the tangential speed is plotted against time, and as a matter of convenience, zero is the time when the needle reaches the axis of the record. To compare the performance at the two speeds for a particular outer groove diameter, the curves are shifted laterally to align the points corresponding to the outer groove diameters, and the zero is shifted to this actual starting point. The pairs of lines corresponding to 12in and 10in records resulting from this operation are shown in Fig. 8, and indicate the critical points already mentioned. Graphs of this kind have been used, in conjunction with the inverse fourth power conversion, to calculate the curves of distortion for various record diameters shown in Fig. 9. In each case, the starting groove is taken as having a diameter half an inch less than the nominal outside diameter of the record.

Summarizing, it can be stated that:

(a) 12in records can be played at either 33⅓ or 45 r.p.m. with good quality to 18 minutes. At 45 r.p.m. the 10 inches per second limit is reached at just over 20 minutes: at 33⅓ r.p.m. this limit is extended nearly to 22 minutes. The rise of distortion is illustrated in Fig. 9(a).

(b) 10in records can, in the extreme, be played to 14½ minutes at either speed, but the last 4 minutes of playing will have noticeably better quality on the 45-r.p.m. record. The lower distortion in the latter case is indicated in Fig. 9(b).

(c) For smaller records, the higher turntable speed is unquestionably better: by this means popular 5-minute recordings can be made comfortably on 7in discs. The advantage is clearly shown in Fig. 9(c).

In deducing the minimum groove velocity we have tacitly assumed that the techniques of recording and

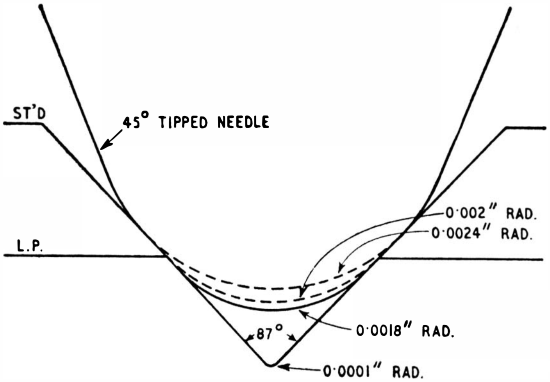


Fig. 10. Standard and microgroove sections superimposed with needle tips of different radii.

processing have kept pace with the reduction of needle size. Results already achieved show that this is in fact possible, but the process requires an increase in skill and supervision, and adds considerably to the production difficulties.

If the choice of turntable speeds were completely free, it would still be difficult to arrive at a definite optimum, because the relative commercial importance of short and long recordings exerts so much control on the choice.

It is impracticable to use the optimum speed where the record is smaller than 8in, because this, after allowing for a run-off groove, would leave an inadequate label diameter. For an 8in record, the optimum varies from 60 r.p.m. to 50 r.p.m. according to the quality permitted. The higher speed should be deprecated, however, partly because it allows no margin for squeezing a little more on to a record (which is quite justifiable where the record ends with a quiet passage), and partly because it is very uneconomical for 12in records. The highest speed that should be considered is therefore 50 r.p.m.

At the other end of the scale, the optimum for 12in records varies from 40 r.p.m. to 33⅓ r.p.m. according to quality, but the loss due to using 40 r.p.m. is, in any case, small. The range of choice therefore lies between 40 r.p.m. and 50 r.p.m. It should be biased to one end or the other of this range according to the relative importance of large and small records respectively.

The Use of Universal Needles

In this report no account has been taken of the American proposals for truncated or other universal needles, although we appreciate the practical convenience of such a needle. Most recording companies are now cutting the 78 r.p.m. type of record with a radius at the bottom of the groove of 0.001in, but it must be remembered that there are a large number of records in circulation which have a bottom radius of at least 0.002in. A universal needle will not necessarily ride on the straight walls of a groove unless the width at the points of engagement is less than 0.0024in (for microgroove records) and simultaneously greater than 0.0028in (for the older 78 r.p.m. records). It follows that, in one case or other, the needle will ride on surfaces which are not accurately controlled, and noisy results will be obtained. These points will be clear from an inspection of Fig. 10.

Apart from this noise, a needle with a tip of radius 0.002in, playing a microgroove record, will give four times the tracing distortion of the standard (0.001in radius) microgroove needle.

An elliptical cross-section point with a small radius of curvature at the contact edge would reduce the distortion, but with a principal radius of 0.002in would contact the microgroove at the shoulder, which is not desirable.

I would like to thank Mr. R. E. Spencer for collaboration in its preparation.

FREQUENCY TEST RECORDS

Calibration Methods Discussed by the B.S.R.A.

IN the past, standard test records have been taken more or less for granted as the basis for comparison of pickup performances. The use of vinyl plastic materials for pressing new test records has, however, shed some doubt on the validity of many earlier assumptions, and to ventilate the matter thoroughly, a discussion was held in London on March 16th by the British Sound Recording Association.

In opening the discussion, H. Davis, M. Eng., M.I.E.E. pointed out that the voltage output from the terminals of a pickup represented the performance of the combined system of pickup and record. When a record groove is traced by a spherical stylus tip, the pressure at the point contact is theoretically infinite; in practice some deformation of the groove wall always takes place until the contact area is sufficient to reach equilibrium. One consequence of this deformation is that a compliance is added to the equivalent mechanical circuit of the system, and the top resonance frequency is usually lowered. In addition to deformation due to the weight of the pickup head, there is the driving force working against the mechanical impedance at the needle point. This force could be very high, and at high frequencies accelerations of the order of 100*g* were possible, even though the groove deflections were small.

Unless mechanical impedances were known to be negligibly small, it would be better to specify a pickup by a family of curves taken in a variety of test record materials and to say that the performance lies within these limits.

In the discussion which followed, various basic methods of measuring the depth of modulation were discussed, including microscopic examination (difficult at high frequencies where amplitudes may be as small as 10^{-6}in); exploration at low speed with light stylus pressure and a displacement micrometer; measurement of voltage output from a pickup at the resonance frequency of the armature and its supporting compliance where mechanical impedance is a minimum, the speed of the turntable being varied inversely as the nominal frequency (working at one frequency eliminates the pickup characteristic); and the Buchmann and Meyer optical reflection method. Several