A RECORD CHANGER AND RECORD OF COMPLEMENTARY DESIGN*

By

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Summary—*This paper describes a record changer and a record designed to accomplish fundamental improvements in the phonograph. The practical and theoretical limitations of other systems have led to the establishment of design and performance objectives for a new system. The accomplishment of these objectives as they apply to the 45 rpm record changer and record is discussed.*

Introduction

When the phonograph and record industries had their commercial beginnings almost a half century ago in the Camden machine shop of Eldridge Johnson, the size of the records and the rotational speed of the turntable were established on a basis which was largely a matter of experimental compromise based on the state of the art at that time. The standards which finally evolved (10 and 12 inches for diameter, and 78.26 revolutions per minute for speed) have remained unaltered for many years. While there have been some noteworthy refinements of record making and playing techniques, these were accomplished within the pre-established limitations of record size, groove dimensions, and turntable speed. Record changing mechanisms, in particular, have been handicapped by the requirement that they accommodate both 10-inch and 12-inch records. Further, records have been costly, fragile, subject to wear, of limited quality, and inconvenient to handle and to store. The result of this situation has been that a truly satisfactory performance seemed to be unattainable within the limitations of the system as established. It, therefore, became evident that an entirely new approach was indicated, namely, one specifically designed to eliminate these problems and limitations.

Experience has shown that any major change in an existing, long-established system must do more than solve problems related to the accomplishment of just satisfactory performance. It might be stated that such a change can only be justified if its accomplishments reason-

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ably approach the requirements of an ideal system. About seventeen years ago there began a program aimed at a fundamental improvement in the reproduction of recorded music. Unhampered by any previous restrictions, attempt was made to develop an ideal method of bringing recorded music into the home. Factors of cost and convenience to the customer, playing time, record life, freedom from distortion and numerous technical considerations were established with the "ideal" being the objective. Some nine years of research and experimentation culminated in a new record playing means which, after eight more years of testing and refinement, finally emerged in a record changer and record to be discussed in this paper.

Factors Influencing Record Changer Design

As long as records were played manually, the two diameters (10-inch and 12-inch), the variations in the dimensions of the starting, lead-in, lead-out, and tripping grooves, and the variations in record thickness were comparatively unimportant. However, with the advent of automatic record playing devices, these dimensional variations became important since they seriously complicated the mechanical design of record changers. Over a period of years the record industry standardized the physical dimensions of the 10-inch and 12-inch records. Unfortunately, standardization did not solve the fundamental problems which confronted the record changer designer, since they are associated with the basic design of the record. Considered solely from the standpoint of record changer design, these problems are due to the fact that the record changer is required to operate with records:—

1. Of constant thickness over their entire area,
2. Having a small center hole,
3. Of two different diameters.

All record changers require a selecting mechanism of some sort to separate individual records from the stack. With records of constant thickness, all practical designs of selecting means cause some damage to the edge, body, or center hole area since the records have to be forced apart or slid one against the other to effect selection. With a small center hole and the heavy records commonly used, high stresses occur around the center hole and record damage results. A small center hole does not permit record stability on the spindle without edge support or complex spindle mechanism. Further, the small hole makes loading difficult.

The necessity of accommodating records of two diameters brings about record changer complexity and customer inconvenience. The very magnitude of the diameters makes the record changing mechanism big. Cabinets to accommodate such record changers and also provide record storage become large and therefore expensive. The relatively high rotational speed of the turntable necessitates the use of speed reducing mechanism to give the record changer time to perform its several functions reliably.

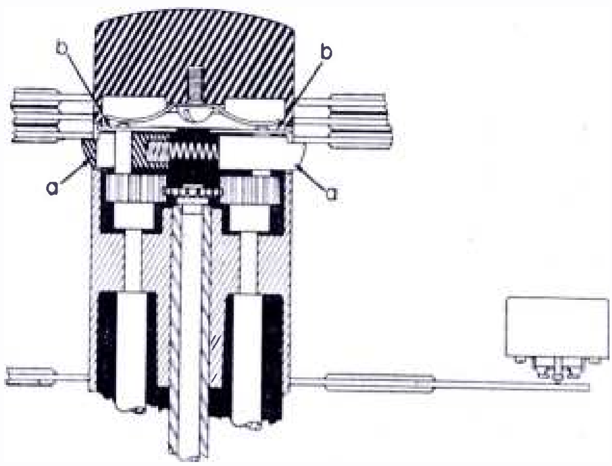
Determination of the Record Changer Design

The solution to these problems, when considered against the ideal of minimum space requirements, minimum cost, maximum performance, and maximum convenience of customer operation, dictated a major change from existing practice. After study of the problem, it was concluded that a simple record changer design could be accomplished if the following conditions were satisfied:—

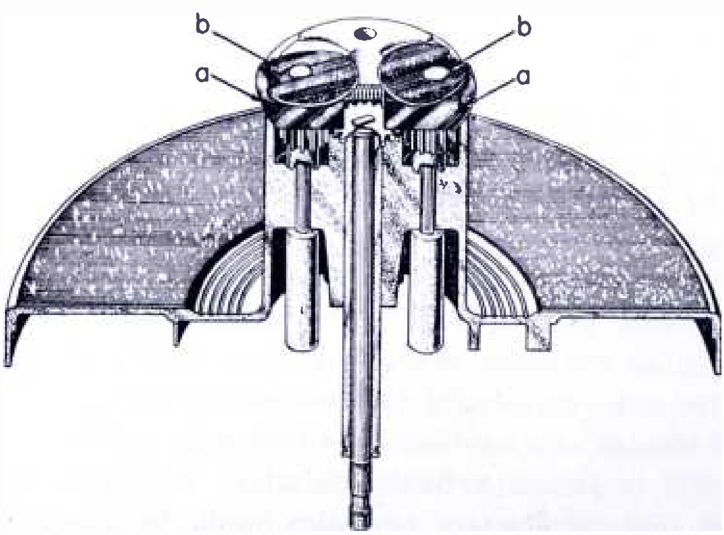
1. A large center spindle housing the separating means. It was found that a 1½-inch diameter spindle would house an economical selecting mechanism, provide adequate record stability on the spindle without external support, and make for easy loading of records on the spindle.
2. Provision of a depressed area around the center hole of the record so that the selector blades would not touch the records during the separating operation.
3. A single diameter record having fixed dimensions for starting and tripping grooves so as to reduce record changer complexity.
4. A small diameter record, rotating at a low speed. The small diameter results in a reduction in size of the record changer. It also permits a decrease in length of the tone arm and thus decreases its inertia. This decreased inertia of the tone arm permits a reduction in cycle time since the low-inertia tone arm may be moved more rapidly during the change cycle. Then by choice of a low rotational speed, it is possible to accomplish the complete change cycle in one revolution of the turntable. The cycling cam may thus be made integral with the turntable, eliminating the speed reducing means. With such a design it was found by experiment that the cycle time could be reduced to 1.2 seconds as a minimum, but that some additional time was desirable to provide reliable operation. It was therefore concluded that satisfactory operation could be expected at any turntable speed below 50 revolutions per minute.

Description of Record Changer

Figures 1, 2, 3 and 4 show the principle of operation of the record selector mechanism. Two oppositely positioned and inwardly retractable shelves (*a* in the four figures) are located in the spindle. In direct association are two outwardly rotatable blades (*b* in the four figures) spaced at a definite distance above the shelves. The design is such that in the playing position (Figures 1 and 2) the shelves extend beyond the periphery of the spindle supporting the record stack and the blades are housed within the spindle. The cycling operation causes the blades to rotate out beyond the outside diameter of the spindle just before the shelves are retracted. Figures 3 and 4 show the positions of the blades and shelves just after the record has been selected. To



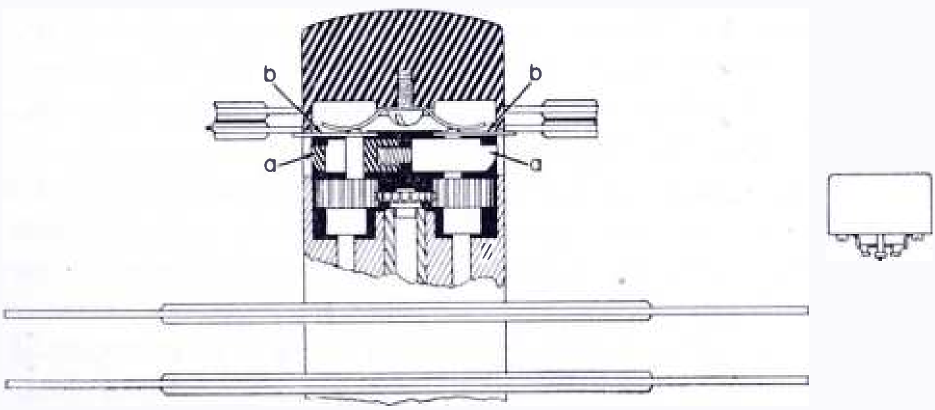
PLAYING POSITION
[OUT OF CYCLE]



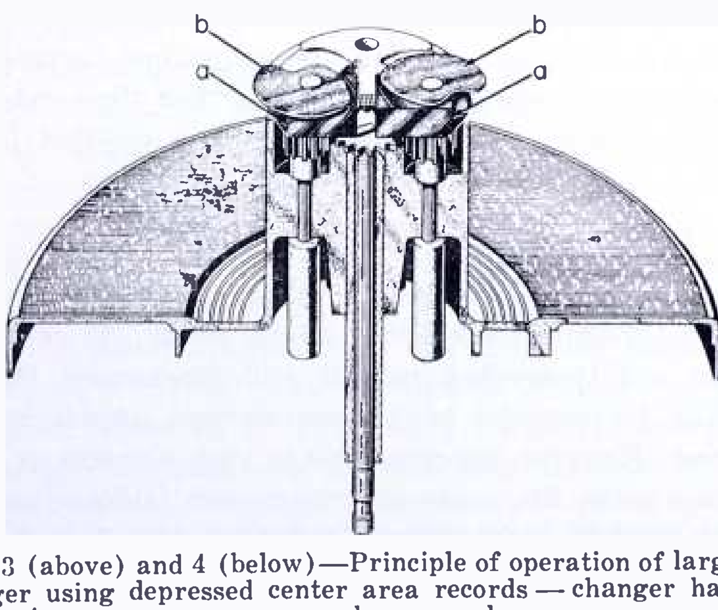
Figs. 1 (above) and 2 (below)—Principle of operation of large spindle record changer using depressed center area records — changer in playing position.

complete the cycle, the shelves move back to their normal extended position just before the blades are rotated back to their normal retracted position.

As may be seen from Figures 1 and 3, the center area of the record about the center hole is depressed on either side of the record, so that, when two records are stacked together, an air space is provided between them. The dimensions of the depressed area and the spacing between the record changer shelf and blade are such as to bring the center of the blade in line with the center of the air space provided between the records. This design offers a distinct advantage in that the records are not knived or otherwise separated, or even touched by the blade during the selecting operation. The aforementioned shelves



SEPARATING POSITION
[ONE HALF THROUGH CYCLE]



Figs. 3 (above) and 4 (below)—Principle of operation of large spindle record changer using depressed center area records — changer half way through change cycle.

are held outward by a spring and their lower portion is shaped so as to be contained within the body of the spindle. This design causes the shelves to be cammed inwardly when records are removed from the turntable. The large diameter spindle and record center hole result in easy loading of the record changer, and the retractable shelves result in easy unloading.

The pickup unit, tone arm and tripping mechanism are designed to be consistent with the requirements of the record. (See SELECTION OF DESIGN PARAMETERS below.) The tripping mechanism is of particular interest. It is designed so that the work to trip the mechanism into cycle does not require any appreciable force between the reproducing stylus and the record groove. A small lever having very low friction is moved, by the inward motion of the tone arm, to a specific position where a lug on the turntable picks up the lever and causes it to cam the mechanism into cycle. The work of putting the mechanism into cycle is thus supplied by the moving turntable rather than by the pickup stylus and record groove.

Record changer tripping mechanisms of the common diameter type are well known for their reliability of operation and simplicity of design. With this type of trip the record can end in a concentric finishing groove rather than the ⅛″ eccentric finishing groove commonly employed. This is of a very definite advantage as the finishing grooves can be cut with same cutting stylus as used for recording and without removing the wax or lacquer from the recorder. Furthermore, the complexity of cutting the eccentric finishing groove on the recorder has resulted in the practice of transferring the wax or lacquer to a special machine designed for that purpose. This practice requires extreme care to prevent damage to the recording and to produce a quiet groove as another cutting stylus is used. For these reasons a common diameter type of tripping mechanism was selected for the record changer.

FACTORS INFLUENCING RECORD DESIGN

With the requirements established for an improved record changer, consideration was given to the existing record design. 78 revolution-per-minute ten- and twelve-inch records still represented the best available medium for recorded home entertainment considering convenience and cost. However, improvements in such elements as record breakage, surface noise, life, consumer convenience (storage and handling), and reproduction quality were highly desirable. Record breakage has been a problem to manufacturer, dealer and consumer ever since the present design of 78 revolution-per-minute records was adopted.

The advent of synthetic thermoplastic resins made it possible to produce unbreakable records.[1] However because of high raw material costs, such resins were not economically practical to use for commercial records.

Record surface noise has also come in for its share of criticism and has a long history. In the past, many factors have contributed to its production; recording materials, cutting styli, metallizing and plating processes, and record compositions. Over the years, improvements in all these elements have been made until, in recent years, the particle size of the mineral fillers used in commercial record compositions has largely determined surface noise. The introduction of the lightweight jewel-point pickup and the frequency balance developed for home instruments just before the war, further reduced the apparent loudness of record surface noise and resulted in quite acceptable performance on home instruments. However, for reproduction with increased frequency ranges, the surface noise of the average commercial record composition is higher than desirable. The elimination of mineral fillers from shellac type compositions is impractical since it results in an extremely brittle, poor-wearing composition; even a reduction in filler particle size seriously increases brittleness. Further, the noise reduction that can be obtained by using the finest available fillers does not approach that obtained with unfilled resins. The solution to this problem is the same as breakage; the use of unfilled synthetic thermoplastics and again economics enters. Toughness, which results in greatly increased record life, is another characteristic of many of the synthetic thermoplastic resins that makes their use desirable in phonograph records.

It is obvious that for an economic solution of these problems, the amount of material in the record should be reduced and that this is compatible with the requirements of improved record changer design and reduced storage space. A drastic reduction in record size was therefore indicated as a major design requirement.

High fidelity reproduction of recorded sound has been an engineering objective for some time. It has been shown[2] that with a purely acoustical system (where noise and distortion are absent) a definite preference is shown for an unrestricted frequency range. It appeared desirable, therefore, in designing a completely new record, that the parameters be chosen so as to reduce inherent distortion to a minimum.

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[1] F. C. Barton, "Vitrolac Records," *Jour. Soc. Mot. Pic. Eng.*, Vol. 18, pp. 452-460, April, 1932.

[2] H. F. Olson, "Frequency Range Preference for Speech and Music," *Jour. Acous. Soc. Amer.*, Vol. 19, No. 4, pp. 549-555, July, 1947.

The major causes of distortion in disc records have been: first—polishing the metal parts in the plating operations, and second—the inability of the stylus to trace the recorded groove. The effect of the first has been recognized for some time[3] and, through the development of improved plating methods, completely eliminated in good manufacturing plants. The second, tracing distortion, has also been known for many years[4,5] but comparatively little work has been done to evaluate it subjectively. Rather than attempt to determine a "tolerable" value, it was considered advisable to limit distortion to less than "perceptible" and a specification was therefore set up that:

> "The maximum tracing distortion in any portion of the record shall not be more than is barely perceptible to trained observers when the record is reproduced through a wide-range audio system having overall response extending to 15 kilocycles."

The two-frequency method of distortion testing has proven to be a powerful tool[6,7]. Investigations carried on during the past several years have shown that this method gives excellent correlation between measurements, theory and listening tests[3]. It was therefore decided to use it in this work. In cooperation with engineers of the National Broadcasting Company, voice and music recordings were made and processed under a variety of conditions. Intermodulation frequency bands (400-4000 cycles) were recorded at the beginning and end of each record at a velocity equal to the peak velocity of the speech or music. It was observed that in all cases where the intermodulation distortion measured less than 10 per cent, no aural distortion was perceptible when the records were reproduced on wide-range equipment, while conditions which produced measured values above 10 per cent also produced aural distortion. It was also observed that distortion was audible in the last third of well-processed high-quality 12-inch commercial records when similarly reproduced, and that a comparable condition obtained with transcription records.

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[3] H. E. Roys, "Intermodulation Distortion Analysis as Applied to Disc Recording and Reproduction Equipment," *Proc. I.R.E.*, Vol. 35, No. 10, pp. 1149-1152, October, 1947.

[4] J. A. Pierce and F. V. Hunt, "Distortion in Sound Reproduction from Phonograph Records," *Jour. Acous. Soc. Amer.*, Vol. 10, pp. 14-28, July, 1938.

[5] W. D. Lewis and F. V. Hunt, "A Theory of Tracing Distortion from Phonograph Records," *Jour. Acous. Soc. Amer.*, Vol. 12, pp. 348-365, January, 1941.

[6] J. G. Frayne and R. R. Scoville, "Analysis and Measurements of Distortion in Variable-Density Recording," *Jour. Soc. Mot. Pict. Eng.*, Vol. 32, p. 648, June, 1939.

[7] J. K. Hilliard, "Distortion Tests by the Intermodulation Method," *Proc. I.R.E.*, Vol. 29, pp. 614-620, December, 1941.

In their paper on tracing distortion, Lewis and Hunt[5] give an equation (Equation (30), page 356) for the distortion resulting when two frequencies are combined. It has been shown[8] that
Per Cent Intermodulation =

$$\frac{\frac{\pi^2}{4}\frac{r^2u_1{}^2u_2}{S^4}\left[(2f_1+f_2)^2+(2f_1-f_2)^2\right]}{u_2-\frac{\pi^2}{2}\frac{r^2f_2{}^2}{S^4}\left(\frac{u_2{}^3}{2}+u_1{}^2u_2\right)}\times 100$$

u_1 = lower frequency lateral velocity (peak)

u_2 = upper frequency lateral velocity (peak)

r = reproducing stylus radius

f_1 = lower frequency

f_2 = upper frequency

S = groove velocity

Figure 5 shows the calculated intermodulation distortion for 12-inch commercial and 16-inch transcription records using the following conditions:

	12-inch Commercial Records	Transcription Records
Revolutions per minute	78.26	33⅓
Diameter of music start (inches)	11½	15½
Diameter of music end (inches)	3¾	7½
Reproducing stylus radius (mils)	3.0	2.3
Peak recording level (centimeters per second)	22.	14.

It will be noted that in both cases the intermodulation distortion exceeds 10 per cent part way through the record and confirms the listening tests. The cumulative evidence of these tests resulted in the decision to select design parameters for the new record such that the intermodulation distortion at the innermost groove would not exceed 10 per cent.

[8] H. E. Roys, "Analysis by the Two-Frequency Intermodulation Method of Tracing Distortion Encountered in Phonograph Reproduction," Equation (7), p. 268 of this issue.

Selection of Design Parameters

From the equation shown earlier, it may be seen that for a given distortion a reduction of reproducer stylus radius allows a reduction in linear speed of the record and therefore a smaller record. (This is obvious since keeping the ratio of r^2 to S^4 constant requires that $S \propto \sqrt{r}$.) Experience dictated the choice of a 1-mil radius as the minimum for the reproducer stylus and a 90-degree, 0.25-mil bottom radius groove. Since stylus and record wear are dependent on pressure, it was considered desirable to reduce the vertical stylus force. A sapphire was chosen for the stylus in order to achieve long life.

Tests have proven that with a vertical force of five grams, stylus life is equal to or better than that obtained in the present day home phonograph. Unfilled vinyl records reproduced under these conditions show life far in excess of commercial filled compositions played on present day phonographs.

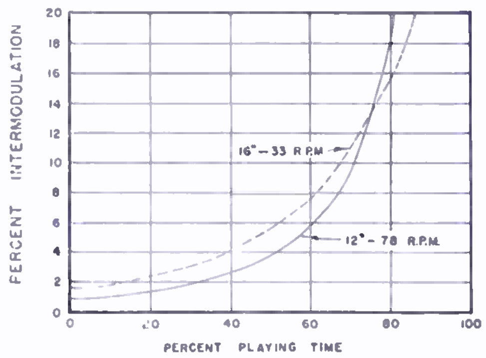

Fig. 5—Calculated intermodulation distortion of commercial and transcription records.

The remaining parameters to be determined in order to design the record are peak recording level, maximum permissible grooves per inch and playing time.

The selection of the first two must be largely a compromise of several factors. Increasing recording level increases signal-to-noise ratio. However, it also increases record size for a given playing time, both because a higher terminal linear speed is required for a given quality level, and because the maximum permissible number of grooves per inch must be decreased. Experience indicated that with the improved processing methods available and the use of unfilled vinyl compositions, highly satisfactory signal-to-noise ratios could be obtained with a peak recording level of 14 centimeters per second (about 4 decibels below standard 78 revolution-per-minute records). Any further reduction in recording level (and therefore signal-to-noise ratio) was considered inconsistent with the objectives of high quality reproduction. This recording level permitted the selection of 275 grooves per inch as a maximum. These selections of recording level and reproducing stylus size resulted in the requirement that the minimum terminal linear speed be 11.5 inches per second for 10 per cent intermodulation distortion in the innermost groove.

While playing time is primarily determined by artistic and commercial considerations rather than technical, it must be discussed here since, in the final analysis, it determines record size. It was pointed out earlier that the use of one size of record, rather than the two now common, would make possible a material improvement in the cost and reliability of the record changer. Unfortunately for the design engineer composers have found it necessary to write selections as short as 1½ minutes and longer than two hours. To determine if any common denominator existed that would minimize musical breaks without being too wasteful for short selections, an analysis was made of the music in the Victor Catalog. Because of its great size, only that portion of the catalog known as "The Music America Loves Best" was chosen.

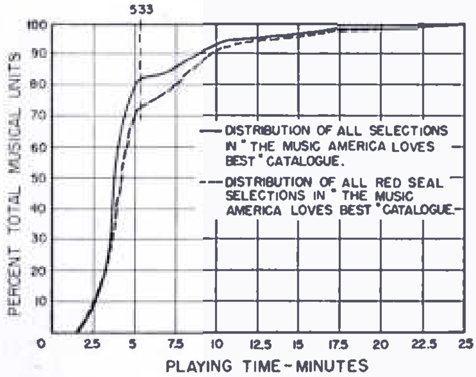

Fig. 6—Playing time distribution of "The Music America Loves Best" catalog, showing the percentage of music units shorter than any specific time.

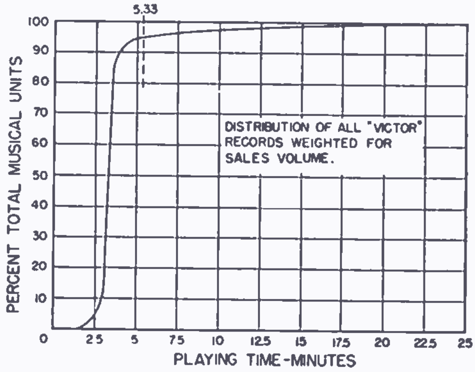

Fig. 7—Playing time distribution of all Victor records showing the percentage of musical units sold which are shorter than any specific time.

This consists of those selections, other than current popular tunes, that show continued popularity. The playing time of each musical unit was determined and cumulative distribution curves prepared. By "music unit" is meant a selection or a part of a work, such as a movement of a symphony, that was written to be played without a break. The "Red Seal" or "classical" portion of this catalog was analyzed separately, since it is in this type of music that long units are most frequently encountered. Distribution curves of both the "classical" portion and the entire "Music America Loves Best" catalog are shown in Figure 6. It is rather surprising to note that 70 per cent of the musical units in the "classical" portion of this catalog are less than five minutes long. It would appear from this that undue weight may, at times, have been given to the importance of long playing time.

Current popular tunes which make up the bulk of record sales must be considered in any determination of record playing time requirements. Figure 7 shows the playing time distribution of all Victor records weighed for sales volume. In this case it will be noted that 96 per cent of all Victor musical units sold have a playing time of less than five minutes. It is felt that, had industry figures been available, an even higher percentage would have been obtained. It was decided, as a result of this analysis, that a playing time of a little more than five minutes, or the same as the 12-inch 78-revolution-per-minute record, would represent the best compromise.

The parameters necessary to design the record have therefore been chosen as follows:

1. Playing time—5⅓ minutes
2. Terminal linear velocity—11½ inches per second.
3. Maximum grooves per inch—275.

Selection of Rotational Speed and Record Diameter

The record diameter to satisfy the above parameters may be determined for any rotational speed from the relations

$$P = \frac{D_0 - D_i}{2R} N \quad \text{and} \quad S_i = \frac{\pi D_i R}{60},$$

where P = playing time in minutes

D_0 = start of recording, inches diameter

D_i = end of recording, inches diameter

R = rotational speed, in revolutions per minute

N = grooves per inch

S_i = terminal linear velocity, inches/second.

A study of the characteristics of the record changer indicated that it would be desirable to provide a landing area of ⅛-inch radial length outside the music grooves. By combining the above equations, substituting the desired parameters and adding the landing area, the relation between rotational speed and diameter may be expressed as

$$\text{D (record diameter in inches)} = 0.0388\,R + \frac{219.6}{R} + 0.250 .$$

While it has been shown[9] that the minimum diameter record is obtained when $D_0 = 2D_i$ or $R = \sqrt{\frac{60\,S_i N}{2\pi P}}$

[9] J. P. Maxfield, U. S. Patent #1,637,082, filed January 17, 1925.

other factors must also be considered in selecting the rotational speed.

The criteria involved are:

1. The record should contain a minimum volume of material (this, as will be shown later, is not necessarily consistent with the minimum diameter constant thickness record).
2. The rotational speed should be selected considering optimum mechanical performance of the record changer.
3. An adequate label area (to provide identification of the music) should be included.

Another factor evolved from the fact that the records are separated from the center and that record changer operation therefore is not affected by the thickness of the outside edge of the record. It is then possible to reduce the thickness of the record in the music area and consideration was given to the design shown in Figure 8(b). This design has two major advantages; first, the volume of material required for a given diameter of record is appreciably reduced; and second, the music areas of adjacent records do not touch in normal handling or playing. This reduces the probability of scuffing the music grooves. It is, however, necessary that the radial length of the label area (A_R, Figure 8(b)) be large enough to provide adequate driving force and preclude the possibility of slippage.

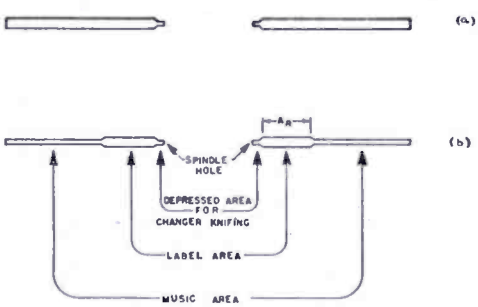

Fig. 8—Cross section of 45 revolution-per-minute records. (a) Constant thickness, (b) Depressed music area.

Earlier in this paper it was pointed out that the maximum permissible rotational speed of the record changer was 50 revolutions per minute, and that to secure reliability of operation, a somewhat lower speed would be desirable. A speed of 45 revolutions per minute was tentatively adopted as a practical maximum. The desirability of making use of one of the two existing standard speeds (33⅓ and 78.26 revolutions per minute) was recognized, and consideration was therefore given to these three speeds (33⅓, 45 and 78.26 revolutions per minute).

Considering the record changer only, no serious disadvantages occur from operation at 33⅓ revolutions per minute. However, as will be shown later, major disadvantages are encountered from the standpoint of the record.

Again considering the record changer alone, operation at 78 revolutions per minute would require the addition of a speed reducing mechanism to enable it to function reliably. This would complicate and add cost to the design and was therefore considered undesirable unless very large advantages would accrue from the standpoint of the record.

A study was then made of the volume of material in the record and the radial length of the label area for different rotational speeds. Considerable study of the changer and of record manufacturing operations resulted in the following decisions:

1. A radial distance of 3/16-inch is desirable between the last music groove and the concentric finishing groove to provide reasonable tolerance for the trip mechanism and allow a very slight interval between the last note and actual tripping.
2. A radial length of 3/16-inch is desirable between the concentric groove and the outside diameter of the thicker center section. This is necessary partly to provide for normal variations in label diameter and label centering but also to allow the metal stampers to be formed to the reverse of the record contour after electroforming. This radial length is sufficient to prevent distortion of the concentric groove by the forming operation and to allow for a taper between the thin and thick sections.
3. The depressed center area of the records which forms the air space in which the selector blades operate should have a radial length of approximately ⅛ inch.

The radial length of the label results from the equation

$$A_R = \frac{1}{2}\left(\frac{60\, S_t}{\pi R} - 2.531\right)$$

or using the previously chosen parameters

$$A_R = \frac{109.9}{R} - 1.265.$$

The radial length of the label and the volume of material in the record for the depressed music area design (Figure 8(b)) are shown in Figure 9. It will be noted that at 78 revolutions per minute the radial length of the label is approximately 1/10 inch and it is therefore obvious that even though the record volume approaches a minimum at this speed, such a record design is impractical since the label area is much too small either to provide adequate traction or to allow space for printing. It will also be noted that as the speed is reduced the volume of material required increases rapidly and that therefore 33⅓ is a much less efficient speed than 45 revolutions per minute.

Careful testing of large numbers of records played with a pickup of 5 grams stylus force under different conditions of stylus and record wear, developed the fact that the minimum label diameter to provide adequate traction was 3½ inches. This required that the minimum diameters of the concentric finishing groove and the last music groove be 3⅞ inches and 4¼ inches respectively. This diameter provides a radial length of about ⅞ inch, which is sufficient for printing requirements.

Figure 10, curve b, shows the relation between record volume and rotational speed of the depressed music area record with a label diameter of 3½ inches. Minimum volume for this design is obtained at 51½ revolutions per minute. Since the diameter of the last music groove cannot be decreased below 4¼ inches, operation at higher speeds requires an increase in the outer diameter of the record and results in the essentially straight portion of the curve. While it is true that increased terminal velocity is obtained and results in a theoretical reduction in distortion, it is considered that this is an academic point since no subjective improvement would be noticed.

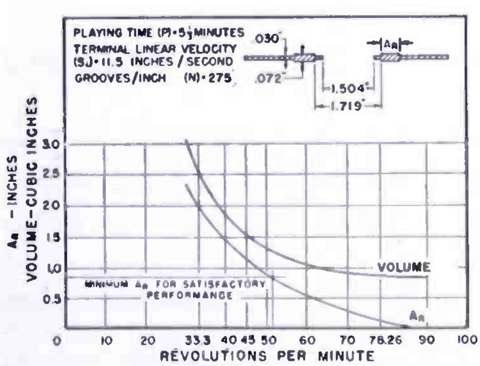

Fig. 9—Relation of record volume and radial length of label to rotational speed—depressed music area design.

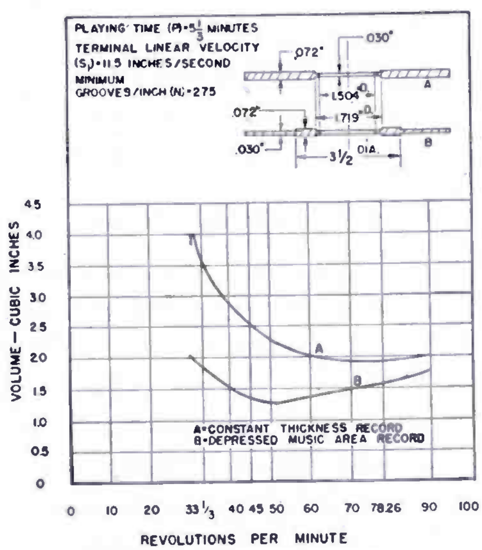

Fig. 10—Relation of record volume to rotational speed for (A) Constant thickness record, (B) depressed music area record with constant diameter label.

It was pointed out earlier that 45 revolutions per minute had been tentatively selected as the maximum practical rotational speed for the record changer. At this speed, the minimum music diameter is 4.9 inches. By utilizing the remaining music area of the record (to the limiting diameter of $4\frac{1}{4}$ inches), a playing time of $7\frac{1}{4}$ minutes is possible with a terminal groove velocity of 10 inches per second. While the reproduced quality at the inside of such a record will be inferior to the criterion of 10 per cent intermodulation distortion, it is, however, superior to that obtained from 78.26 revolution-per-minute records. Such a design might be of interest for use with "popular type" or "children's" records, since it provides quality adequate for this type of program material.

Figure 10 also shows the volume of the constant thickness record as a function of revolutions per minute. It is interesting to note that the depressed music area record has a smaller volume for any speed above 31 revolutions per minute than the constant thickness record at its theoretical optimum speed.

The advantages and disadvantages of the three speeds in record designs that satisfy the previously established parameters ($5\frac{1}{3}$ minutes playing time, 275 grooves per inch, $11\frac{1}{2}$ inches per second terminal velocity) may be listed as follows:

78.26 revolutions per minute

1. A speed reducing mechanism must be incorporated in the record changer increasing its complexity and cost.
2. The minimum volume depressed music area design is impractical. If the constant thickness design is used, more material is required than is used by the depressed music area design at the other speeds under consideration.
3. The label area in the constant thickness minimum volume design is entirely inadequate.
4. The diameter of a $3\frac{1}{2}$-inch label depressed music area record would be $\frac{5}{8}$ inch greater than at 45 revolutions per minute and require 17 per cent more material.

$33\frac{1}{3}$ revolutions per minute

1. The record diameter must be increased by $1\frac{1}{4}$ inches and the volume of material by 33 per cent over that required at 45 revolutions per minute. The limiting groove velocity of 11.5 inches per second is reached at a diameter of 6.6 inches. This diameter is greater than the diameter of the first music groove of the 45 revolution-per-minute record.

45 revolutions per minute

1. The volume of material in the record is less than that required at either $33\frac{1}{3}$ or 78.26 revolutions per minute.

2. With the depressed music area design, which reduces record scuffing, the diameter is 6⅞ inches compared to 8⅛ inches at 33⅓ or 7½ inches at 78.26 revolutions per minute.
3. The record changer design provides reliable performance.
4. A playing time of 7¼ minutes may be obtained at a reduced terminal quality (though superior to 78 revolution-per-minute records).

Based on the above considerations, the speed of 45 is obviously superior to either 78.26 or 33⅓ revolutions per minute, and was therefore chosen for this system.

Recording and Reproducing Characteristics

The recording characteristic used for these records is shown in Figure 11. For use in calibrating reproducing systems, a frequency

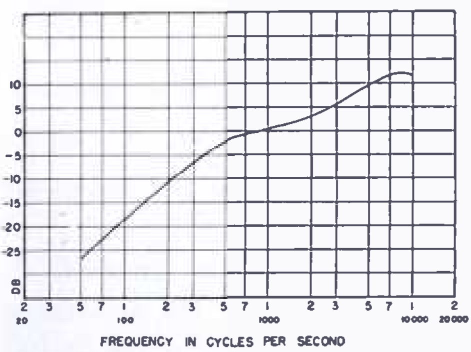

Fig. 11—Overall frequency characteristic (microphone pre-amplifier to cutting stylus) used in recording 45 revolution-per-minute records.

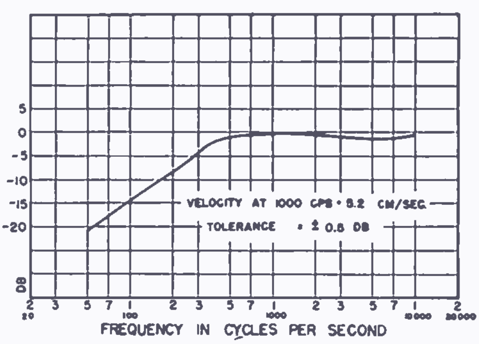

Fig. 12—Average calibration of 45 revolution-per-minute test record 12-5-31.

record has been prepared. Calibrations by both the variable speed turntable and the light pattern methods were found to be in good agreement. The calibration of the record is shown in Figure 12.

Conclusions

In Figure 13, the finished record changer and records are pictured. It is believed that the system described here represents a basic advance in disc record reproduction. The desired improvements in quality, both noise and distortion, size reduction, long life, simplified and rapid record changer operation and elimination of record breakage have been achieved. This record meets the requirements for high fidelity reproduction.

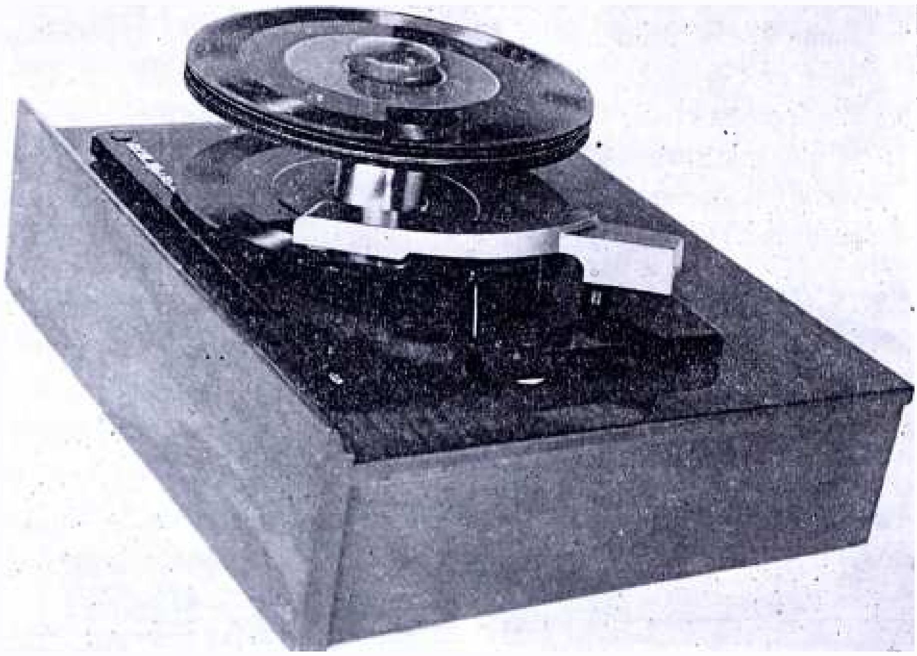

Fig. 13—Record changer and mounting with records in operating position.

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