Recent Advances in Wax Recording [1]

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SYNOPSIS: This paper considers chiefly the frequency-response characteristics and limitations of the lateral cut "wax" record. It shows that the frequency range from 30 to 8,000 cycles can be recorded and reproduced from the record with practically negligible deviation from a flat frequency-response characteristic. The paper brings out the ease with which the record can immediately be replayed from the "wax" as an aid in assisting the artist to obtain the best results. A brief description is given of commercial processing methods including both plating and pressing. These methods give essentially a perfect copy of the original "wax." The time required for this work has been considerably reduced of late so that a test pressing can be obtained within three hours of the cutting of the original "wax."

IN the recording and reproducing of sound by the so-called "electric" method with the "wax" disc, the process may be considered as consisting of eleven steps. In order, these are: (1) studio, with its acoustic conditions, (2) microphone, (3) amplifier, (4) electro-mechanical recorder, (5) "wax" record, (6) copying or reproducing apparatus, (7) hard record or "pressing," (8) electric pickup, (9) amplifier, (10) loud speaker, (11) auditorium.

With this chain of apparatus the chief problem is that of making the reproduced sound in the auditorium a perfect copy of that in the studio. This is a matter of quality or fidelity of reproduction. There are other problems of cost, reliability, time required, etc., which are important but secondary to that of fidelity. While it may be necessary or convenient to introduce distortion in one of these links to compensate for such unavoidable distortion as may occur in other links, experience shows that it is desirable for the sake of simplicity, reliability and flexibility to reduce such corrective warping to a minimum and to make each step in the process as nearly perfect as possible. Perfection of a complete system may be judged by the practical method of listening to the overall result. It is necessary, however, to analyze each element of the complete system. To do this, other more analytical methods of test and standards of performance must be used. One of the most useful of these is the response-frequency curve. In order that all frequencies be reproduced equally and that the ordinary faults of resonance be avoided, this must be flat and free from sharp peaks. Good reproduction requires that frequencies from 50 to 5,000 cycles be included without discrimination. If, however,

[1] Presented before Society of Motion Picture Engineers at Lake Placid, New York, September 26, 1928.

the low frequency range be lowered to 25 or 30 cycles, a noticeable improvement will be obtained with some classes of music, whereas if the upper limit be increased to 8,000 or even 10,000 cycles, the naturalness and smoothness of practically all classes of reproduction will be noticeably improved.

A second important requirement in the judgment or analysis of any such system is that the ratio of output to input shall not vary over the range of currents or loudnesses (as well as frequencies) from the minimum up to the maximum used. If this requirement is not met, sounds or frequencies not present in the original reproduction will be introduced. This type of distortion has probably been heard by all of us in listening to an overloaded vacuum tube amplifier and is often referred to as "non-linear" distortion.

A third requirement not entirely disassociated from the first two is that any shifts in the phase relations shall be proportional to frequency.

Our judgment of the degree of perfection needed in sound reproduction systems is changing and growing more critical, so that what seemed excellent yesterday may be only fair today and tomorrow may seem intolerable. It is therefore necessary that our consideration and analysis be continually more searching and fundamental.

Of the eleven links in the chain of apparatus required for electric "wax" recording and reproduction, only five are peculiar to the "wax" method. These are the electromechanical recorder, "wax" record, the copying apparatus, the "pressing" and the pickup or reproducer. The extent to which the "wax" method is capable of the highest quality of reproduction will be disclosed by an examination of these five links. Any consideration of the practical advantages or disadvantages of the method can logically follow this examination into the quality possibilities.

The consideration which follows refers to the so-called "lateral" cut record; that is, a record in which the groove is of constant depth and oscillates or undulates laterally about a smooth spiral. This is the type used in the Western Electric Company disc record type of synchronized motion picture system. Some, but not all of the considerations and conclusions might apply to the "hill and dale" type record. It is not the purpose of this paper to consider the relative characteristics of "hill and dale" and "lateral" "wax" records.

Electromechanical Recorder

It is the task of the electromechanical recorder to take power from the amplifier and drive a mechanical recording stylus. The presentday recorder is a highly developed apparatus based on extensive experimental as well as theoretical studies. A diagrammatic view is given in Fig. 1.[2] Recorders which have been supplied by the Western Electric Company have been designed to operate over a range of frequencies from 30 to 5,500 cycles. A typical frequency characteristic

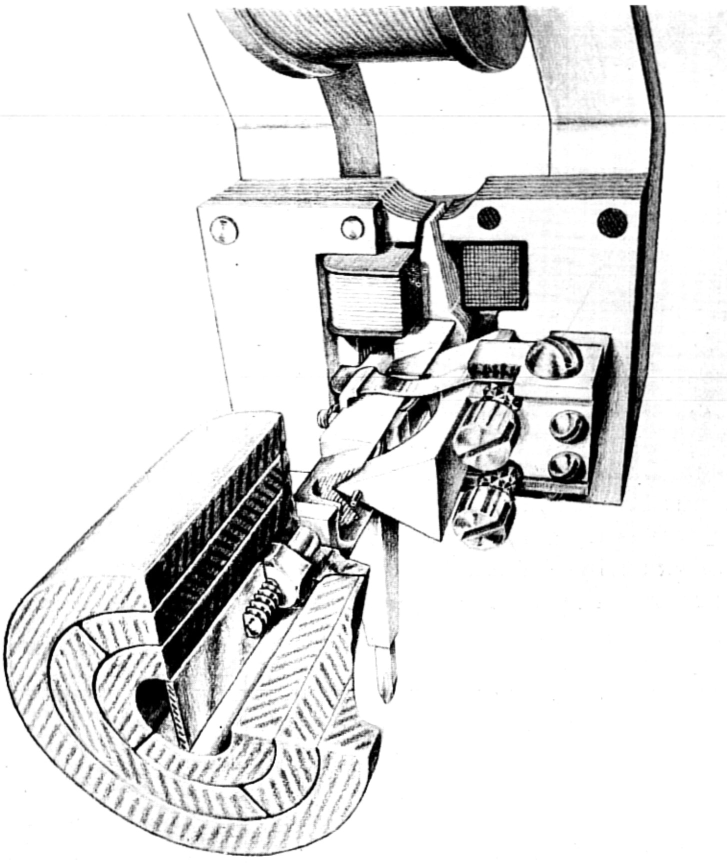

Fig. 1—Diagrammatic view of the electromechanical recorder.

is shown in Fig. 2. The device operates in linear fashion over the range of amplitudes involved in speech and music. As is seen, the response falls off below about 250 cycles. This falling characteristic is necessary in order that the maximum loudness be obtained from a record for a given spacing between grooves without cutting over

[2] "High Quality Recording and Reproducing of Music and Speech," by J. P. Maxfield and H. C. Harrison, presented at 14th Midwinter Convention of the American Institute of Electrical Engineers, New York, N. Y., Feb., 1926.

from groove to groove. In order that a lateral oscillation in a groove may represent constant intensity of sound or a constant energy over a range of frequencies, not the amplitude of the oscillation but the velocity, which is proportional to the product of the amplitude and the frequency, must be maintained constant. With the characteristic shown with these recorders, constant velocity is obtained from about

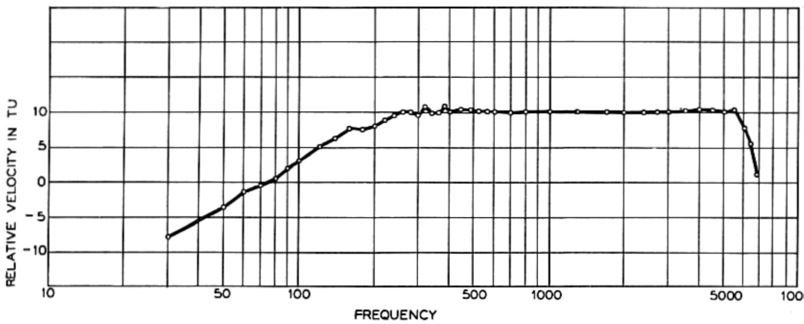

Fig. 2—Typical frequency characteristic of a commercial recorder.

250 cycles to 5,500 cycles. Below 250 cycles an approximately constant amplitude is obtained. If, therefore, sounds of constant absolute intensity are to be recorded over this range of 30 to 250 cycles, there is equal tendency for sounds of the different frequencies in this range to over-cut the record groove. It may be corrected in reproduction by a suitable electric network. Such a network will increase the subsequent amplification required but, as this additional

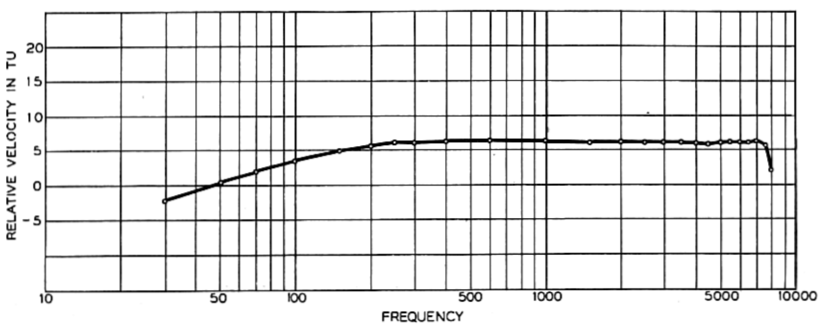

Fig. 3—Frequency characteristic of a laboratory model recorder.

amplification occurs in the first stages, it is not expensive. Practically it has not been found necessary or desirable to introduce such a corrective network since the correction has been largely cared for by the characteristics of the pickups used.

Recent development studies have established the possibility of flattening the response at the low frequency end and of raising the high frequency cut-off of the recorder. Fig. 3 shows a characteristic obtained with such a laboratory model. This shows uniform performance within ± 1 TU from 250 to 7,500 cycles and within ± 4 TU from 30 to 8,000 cycles. Although its immediate practical value might be limited by other portions of the system, this device is of great interest in that it establishes beyond question the fact that an extremely broad range of frequencies can be successfully recorded in the "wax."

The broad, flat characteristic obtained with electric recorders has been made possible by so designing their elements that they constitute correctly designed transmission systems. In such a transmission system, whether it be an electrical recorder or a long telephone line, a correct terminating impedance is required. The load imposed by the "wax" is somewhat variable but fortunately is rather small. It has been found desirable to make the other impedances in the recorder relatively large so as to dominate the system and thus minimize the effects of any changes in the impedance imposed on the stylus by the "wax." The mechanical load used as a terminating impedance and to control the device has consisted of a rod of gum rubber 25 cm. long. Torsional vibrations are transmitted along this rod. The rate of propagation is about 3,000 centimeters per second so that its length is equivalent to an ideal electrical line of about 1,500 miles. The dissipation along this rubber rod is such that a vibration is substantially dissipated by the time it has travelled down the line and back. It thus constitutes substantially a pure mechanical resistance, the magnitude of this resistance being approximately 2,500 mechanical abohms, referred to the stylus point as its point of application.

"Wax" Record [3]

In recording the usual procedure is to use a disc from 1 in. to 2 in. thick and from 13 in. to 17 in. in diameter, composed of a metallic soap with small amounts of various addition agents to improve the texture. This is shaved to a highly polished surface on a lathe. This polished disc or so-called "wax" is placed in a recording machine. In Fig. 4 is shown what is essentially a high grade lathe arranged to rotate the "wax" in a horizontal plane at a very uniform speed in a definite relation to the film with which it is synchronized. The recorder with its cutting tool or stylus is moved relative to the surface of the disc, common phonograph procedure being to record from the outer edge of the disc towards the center, whereas in the Western

[3] "Some Technical Aspects of the Vitaphone," by P. M. Rainey, presented at the meeting of the Society of Motion Picture Engineers at Norfolk, Va., April, 1927.

Electric Company theater system the direction of cutting is reversed. After a record has been cut into the "wax," the "wax" may be handled and with proper precautions readily shipped from place to place.

The shape of the groove varies somewhat in commercial practice. The groove and stylus most commonly used with Western Electric apparatus are shown in Fig. 5. The groove is approximately .006 in. wide and .0025 in. deep. The pitch of the groove is between .010 in. and .011 in. so that the space between grooves is about .004 in. Thus

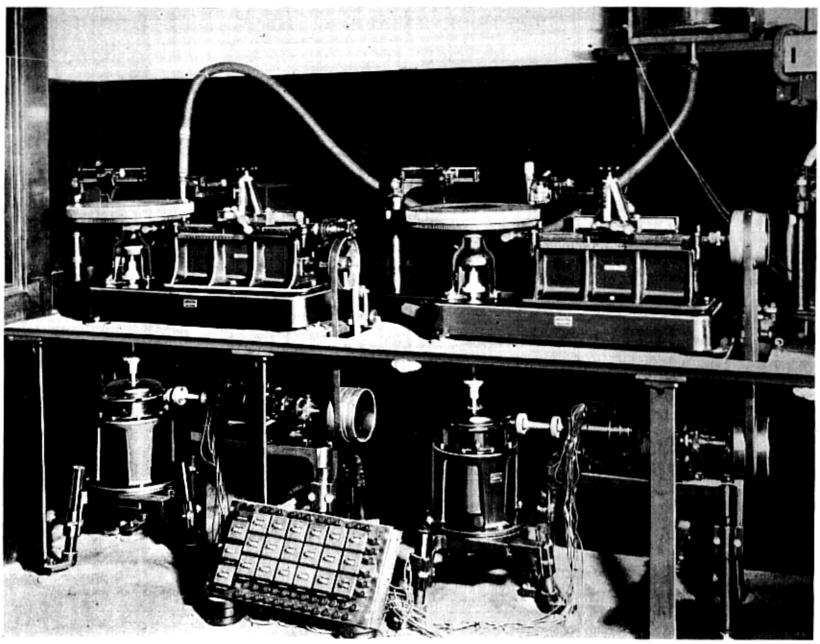

Fig. 4—The recording machine.

the maximum safe amplitude is about .002 in. If this occurs at 250 cycles the corresponding amplitude at 5,000 cycles, assuming constant absolute intensity of sound over this range, would be .0001 in.

It is important that a smooth groove be cut as any roughness in the walls introduces extraneous noise in the reproduced sound. To insure a truly smooth groove the surface of the "wax" must be shaved to a high polish. The texture of the "wax" must be fine and homogeneous which requires not only that the "wax" composition be correct, but that it be operated at the proper temperature. "Waxes" may be obtained commercially which will operate satisfactorily over the ordinary range of room temperature. The "wax" must be levelled in the recording machine with reasonable care. The stylus must be sharp and so ground that the cut will be very clean. The "wax" shaving is removed as cut by air suction. The operator is aided in maintaining the correct depth of cut by the use of a so-called "advance" ball which rides lightly on the "wax" and serves to maintain uniform depth of cut in spite of small inaccuracies of leveling of the "wax" or deviations from planeness. The "advance" ball is adjusted relative to the stylus by observing the cut with a calibrated microscope. A satisfactory operation of the recording machine requires an ordinarily skilled mechanic with reasonable experience.

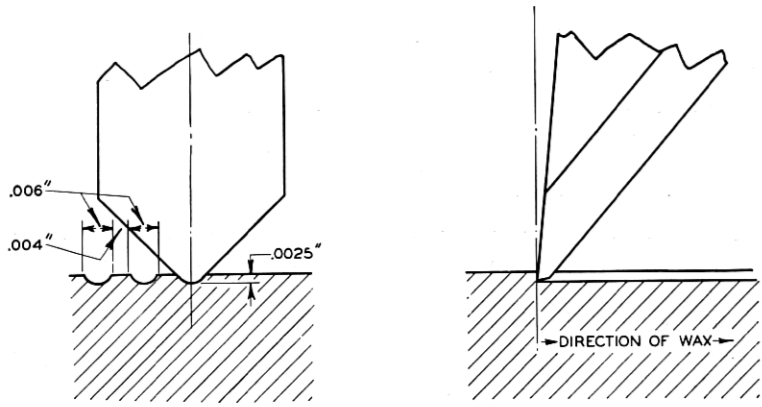

Fig. 5—Recorder stylus.

The rate of rotation is dependent upon the diameter of the record groove which is determined primarily by the length of time which it is desired to have covered by a single disc. The controlling element is the linear speed of the groove past the recorder or reproducer. In the Western Electric system the speed varies from 70 ft. to 140 ft. per minute, in other words, of the same order of magnitude as with the film record. The wave-lengths also are about the same as for a sound record on a film. At the minimum linear speed the half wave-length for a 5,000 cycle wave is .0014 in. If the minimum linear speed is fixed at 70 ft. per minute and the groove spacing is fixed, there is an optimum relation between the size of the record, the rate of rotation and the playing time. This is illustrated graphically in Fig. 6.

After a record has been cut, the sound may be reproduced directly from the "wax" by using a suitable pickup or reproducer. Ordinary reproducers or pickups rest much too heavily on the records to be used on ordinary "wax." That this would be so is obvious from the fact that the vertical pressures between the point of the needle and the record in an ordinary phonograph are of the order of 50,000 pounds per square inch. Obviously any such pressures would destroy a groove cut in soft "wax." These high pressures have been necessary in order that the groove might properly drive the needle point of the reproducer. Reduction of this pressure requires reduction of the impedance offered by the needle point to transverse vibration.

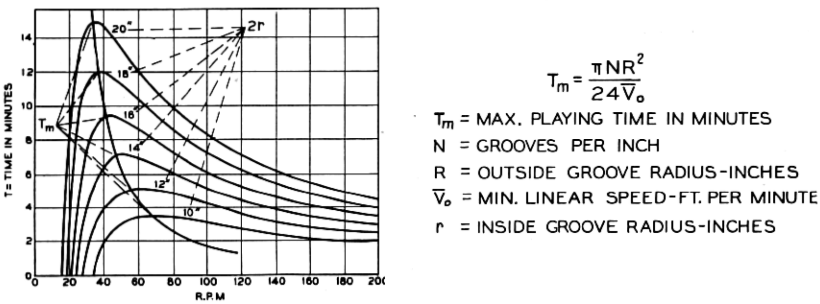

Fig. 6—Relation between playing time and rate of rotation of disc for various values of $R(R = 2r)$.

The design of a suitable "wax" "playback" requires reduction of both the mass and the stiffness of the reproducing system to a minimum. In the past such "playbacks" have failed to reproduce the higher and lower frequencies with much satisfaction. The device shown in Fig. 7 represents a large advance toward ideal reproduction.

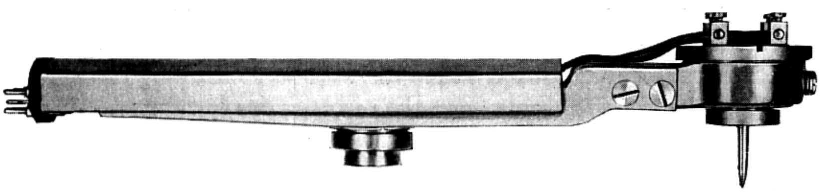

Fig. 7—Playback pickup for "wax" records.

The response of such a device when driven by a "wax" record recorded at constant velocity over the frequency range is shown in Fig. 8. This reproduction is not widely dissimilar from that obtained from finished records with the best electric pickups now commercially available and is sufficiently good to serve as a very valuable criterion in judging the quality of the record. The record may be played a number of times without great injury. The extent of the injury is indicated by the frequency characteristics obtained on successive playings shown in Fig. 9. They show little change in the low frequency response and a loss of about 2 TU per playing at high frequencies. The practical value in studio work of being able to let an artist immediately hear and criticize the results of his own efforts can hardly be overestimated.

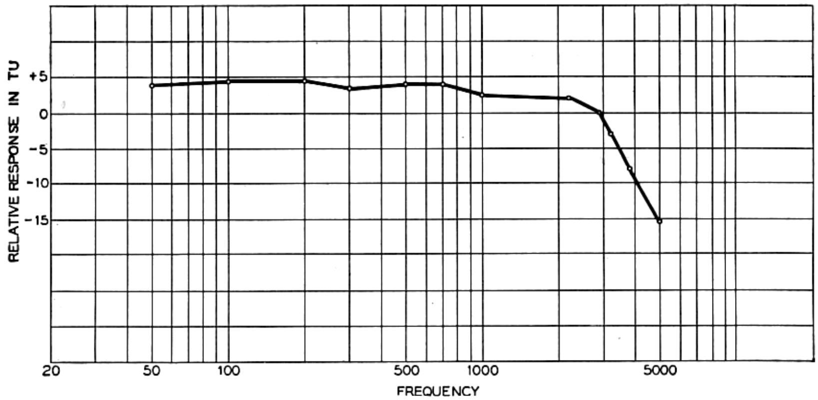

Fig. 8—Response of a "wax playback" driven by constant velocity wax record.

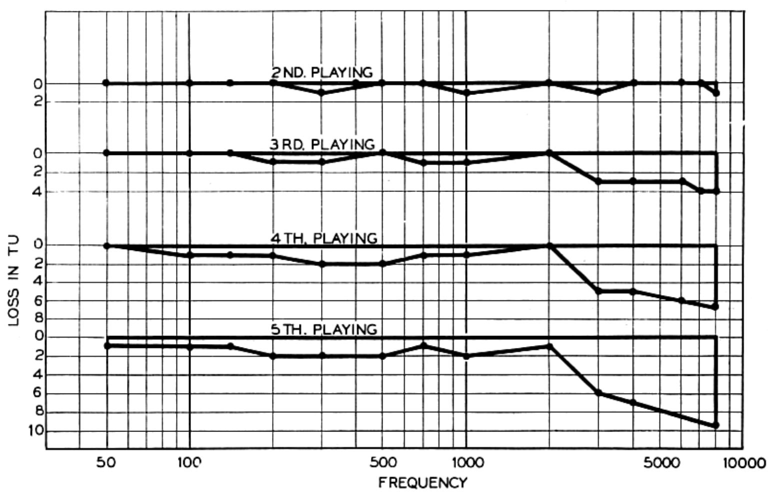

Fig. 9 Loss in response on successive playings of a wax playback driven by constant velocity wax record.

Copying (Processing) of the "Wax" Record

After a groove has been satisfactorily cut into the "wax" record, the usual procedure is to render the surface of the "wax" conducting by brushing into it an extremely find conducting powder. It is then electroplated. The technique in this step varies somewhat with the different companies doing such work, although not in any fundamental manner. The negative electroplate thus made may be used to hot-press a molding compound such as shellac containing a finely ground filler. This first electroplate is called a "master." From it two test pressings are usually made. If satisfactory the matter is then electroplated with a positive, being first treated so that this positive plate may be easily removed. This positive is sometimes called an "original." From this in turn is plated a metal mold or "stamper." From these, duplicate "originals" may be plated and from them, duplicate "molds" or "stampers." These processes involve no measurable injury to the quality of the record and are comparatively simple and extremely safe in practice. By this practice of making a number of duplicates it is possible to safeguard the "master" and insure against any accident which might destroy a valuable record. From a single "stamper" it is not unusual to make a thousand finished pressings. The time required for these operations is such that test pressings are commonly obtained from the "wax" in 12 hours. Recent refinements in the art have reduced the time required so that finished records may, if necessary, be obtained in 3 hours after delivery of the "wax."

Hard Record or "Pressing"

Various materials have been used in making the hard record or "pressing." In some cases the material has been made homogeneous and in others the surface is of a different material from that used in the body of the record. Some have used a laminated structure. There has not, however, been much latitude allowed the experimenter concerned with materials for the hard record. The material has had to be quite hard and, in order to show a reasonable life, it has had to contain sufficient abrasive to grind the needle quickly to a good fit. At the beginning of the run of a new needle due to the small bearing surface, the pressures are very high. They rapidly decrease so that with an ordinary loud steel needle after one minute's wear in the ordinary phonograph, the bearing area is increased to such an extent that the pressure is only about 50,000 pounds per square inch. As the needle continues to wear to a larger bearing surface, the pressure obviously continues to decrease. These high pressures and necessary abrasive characteristics of the record have introduced irregularities which are responsible for most of the extraneous noise commonly known as "surface" or "needle scratch."

The "pressing" copies the "wax" record with a very high degree of accuracy so that if our attention be confined to frequency characteristics alone, the "pressing" shows almost complete perfection.

Moreover, it is cheap and durable, and reproduction of the sounds from this record calls for no fine adjustments or intricate apparatus as has been long evidenced by the broad use of the ordinary phonograph.

The major part of the extraneous or "surface" noise found with this method of reproduction comes from the material of the finished record. Recent progress has been made in reducing this noise. As a result of this, together with refinement in the plating processes, records used with Western Electric Company theater equipment during the last two years have shown a reduction of 3 to 6 TU in "surface" noise. This corresponds to eliminating 50 per cent to 75 per cent of that previously present. It is not necessary to reduce the level of "surface" noise to the zero point but merely to the threshold of audibility under the conditions of minimum auditorium noise which are of interest. This noise masks the surface. Moreover, it is not the absolute amplitude of the imperfection giving rise to "surface" noise but the relative magnitude in comparison with the useful sound amplitudes which counts. Thus, an effective reduction in "surface" could be made if we were willing to use larger records or if we were willing to reduce the playing time of the present records by increasing the spacing of the grooves and the amplitude at which the grooves are cut. Any large reduction in "surface" noise made by a reduction in the irregularities in the record material would open the door to increasing the playing time of a record of given size. There is no known absolute or fundamental reason why further improvements in record materials may not be expected to reduce further the amount of "surface" noise. Moreover, large advances in pickup design open distinctly new possibilities as to reductions in "surface."

It has sometimes been thought that in order to reproduce high frequencies properly, the linear record speed would have to be increased or the size of the needle point reduced. At present the diameter of the bearing portion of a representative needle is about .003 in. whereas, as mentioned before, the half wave-length for a 5,000 cycle wave is .0014 in. The factor determining whether a needle will follow the undulation of the groove is not any consideration of the relative diameter of the needle point and the undulation of the groove but rather the radius of curvature of the needle and the bend of the groove. As indicated before, the amplitude at 5,000 cycles would be only about .0001 in. if sounds of that frequency were as intense as those of lower frequencies (.002 in. at 250 cycles). As a matter of fact, sounds of 5,000 cycles or more in speech or music are characterized by lower intensity than those of lower frequency. If, however, we assume an amplitude of .0001 in. at 5,000 cycles and assume a linear record speed of 70 ft. per minute, then the minimum radius of curvature of the undulation of the groove is .00193 in.[4] With the foregoing assumption, the radius of curvature of the undulation of the groove becomes equal to that of the needle point at about 7,000 cycles. Taking into account the lower intensities of sounds encountered at these high frequencies, it is obvious that present commercial needle points are quite capable of following the high frequency undulations of the groove up to frequencies of at least 10,000 cycles. The limitations of high frequency reproduction commonly found in the past are associated with limitations in the design of the pickup or reproducer and relate either to inability of the record groove to drive the needle point, with resultant chatter, or inability of the pickup structure to transmit high frequency motions from the needle point to the armature.

Electric Pickup

Large advances have been made within the last two or three years in designing electric reproducing structures. The mechanical im-

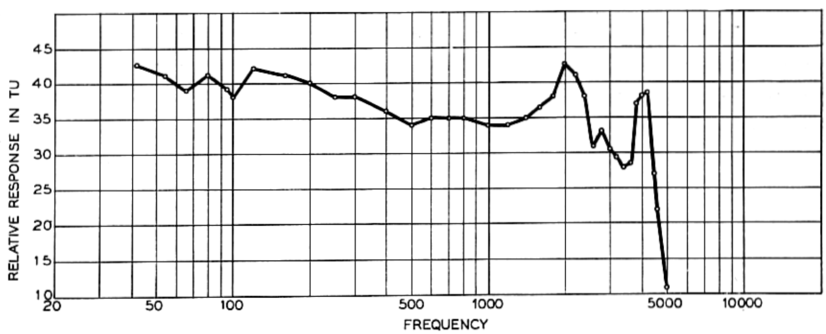

Fig. 10—Response of a 2-a pickup driven by constant velocity pressings.

pedance at the needle point has been reduced so that the needle point truthfully follows the undulations in the groove without necessitating excessive and somewhat destructive bearing pressures. At the

[4] The minimum radius of curvature is computed by the formula

$$R_c = \frac{V^2}{100\pi^2 A f^2},$$

where:

R_c = minimum radius of curvature in inches.

V = linear speed in feet per minute.

A = amplitude of vibration in inches.

f = frequency in c.p.s.

same time the transmitting structure has been so designed that a very broad range of frequencies is properly transmitted from the needle point to the armature. Moreover, proper mechanical loads have been provided so that the motions after transmission are absorbed and hence not reflected back. This is another way of stating the fact

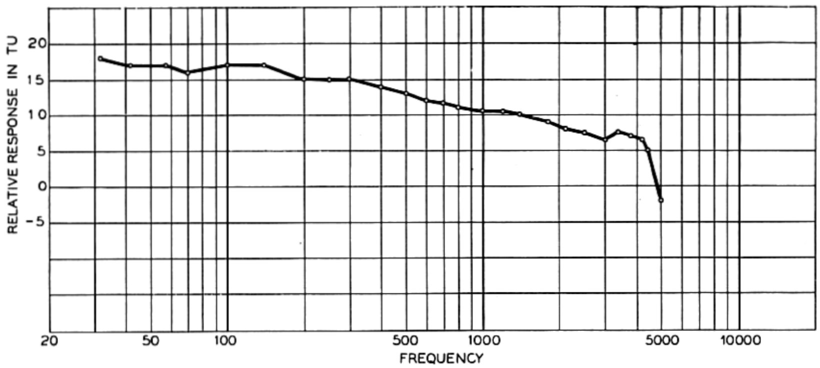

Fig. 11—Response of a 4-a pickup driven by constant velocity pressings.

that resonance as ordinarily considered has been eliminated from these structures.

The curves shown in Figs. 10 to 12 illustrate the steps which have been taken. The pickup shown in Fig. 11 is free from the resonances shown in that of Fig. 10. The resonances present in the earlier

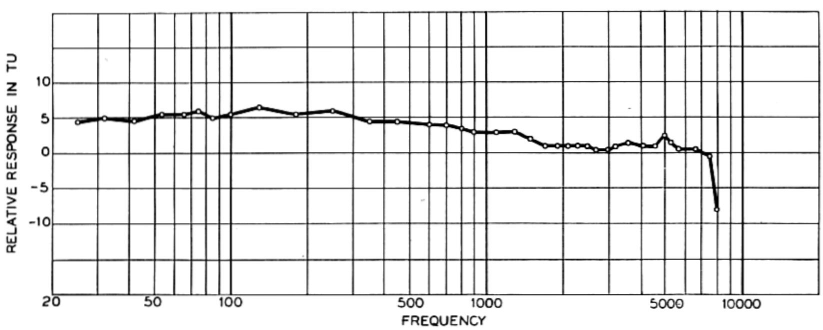

Fig. 12—Response of experimental pickup driven by constant velocity pressings.

pickup involved high needle point impedances in the region of these resonances. These high impedances involved large driving forces destructive both to needle and record. Certain records were injured after only a few playings with this reproducer. The later reproducer is characterized not only by considerably reduced *average* needle point impedance, but, as shown by the curves, the resonance is practically eliminated and hence there is an even greater reduction from the maximum impedance which occurred in the earlier reproducer at resonance. Both needles and records have a relatively long life with the later type pickup, which has been in commercial use for some months. As is seen, the higher frequencies are reproduced in considerably better fashion. A third curve is given in Fig. 12. This was obtained with a more recent experimental model in which a further large reduction in the needle point impedance had been effected and in which, in addition, a very much more rigid, though a lighter structure served to connect the needle point with the armature. This model shows further reduction in wear and tear on the record and very greatly improved reproduction at the high frequency end of the scale.

The application of the processes of sound recording on "wax" to the synchronized film has involved meeting a number of conditions not previously encountered in the phonograph field. One of the most important of these relates to editing, cutting and rearranging of the picture. Various methods have long been used to copy or "dub" a disc record. The prime requirement is that there be no sacrifice in quality. To attain this end records have sometimes been copied at very low speed. This method appears unnecessarily laborious and slow and the results obtained are not altogether satisfactory in the light of possibilities presented by pickups and recorders of the characteristics shown above. Rearrangement of material on records is entirely practicable, portions may be deleted or new portions added either as a whole or the new sounds added to those already on a record—in fact any changes of this type may be made which can be made in the picture.

The detailed technique of "dubbing" appears to offer no serious technical difficulties. The refinement reached and the extent of its future use may be expected to be governed by the demand in the synchronized motion picture field.