BASIC DISC MASTERING

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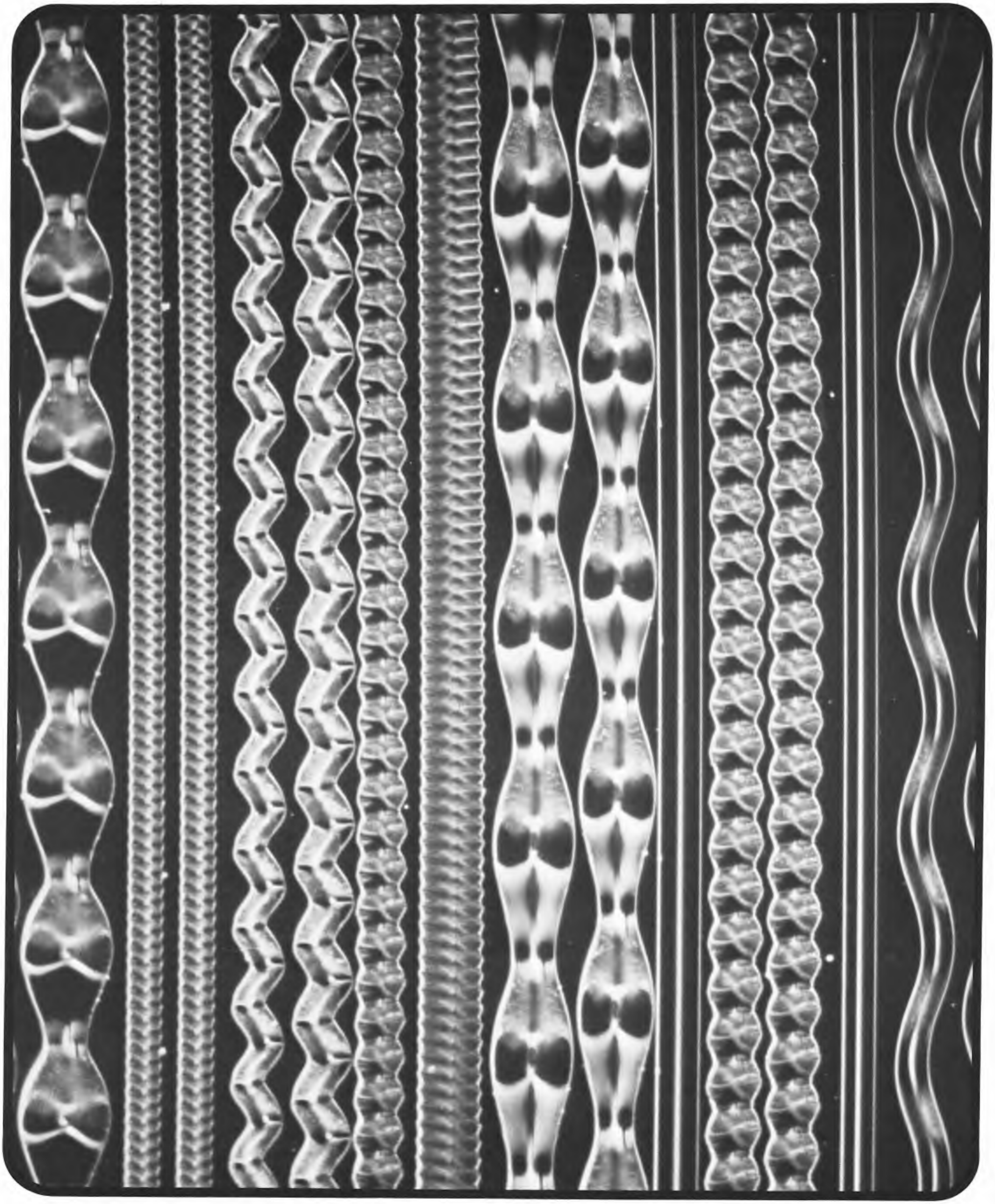
Book design, layout, typesetting, and production art

by Novatype, Glendale, California

Sole U.S. Agent:

Full Sail Recording Workshop

1221 Lee Road, Orlando, FLA. 32810



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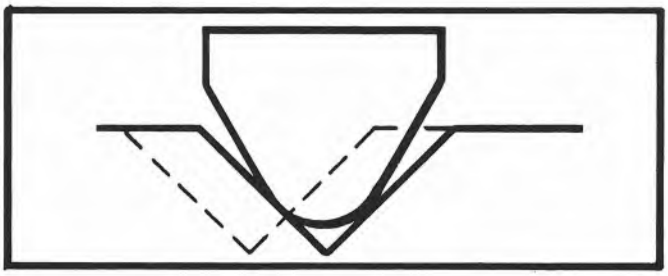
How Grooves Work

A primary need to anyone interested in a close study of the disc recording procedure is a firm and complete grasp of the physical nature of record grooves.

Perhaps the best way to do this is to thoroughly explain how monophonic grooves work first, and then move on to stereo.

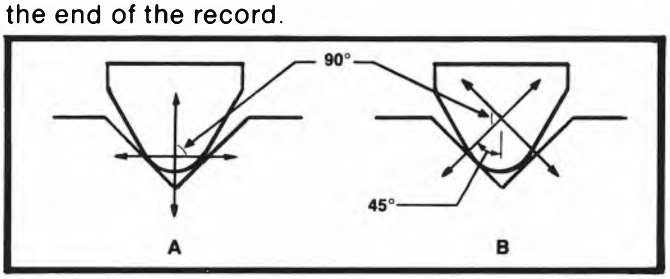


Cross section of a cutting stylus cutting a mono groove, showing the plane of modulation.

Let's feed an IK tone into a mono cutting system: The tone is first received by the cutting amplifier which delivers the power needed to cut the tone to the cutterhead itself. The cutting stylus in the tip of the cutterhead etches the tone as a side to side continuous physical translation in the surface of the acetate master disc. Think of the cutterhead as an electromagnet that responds to the current provided by the cutting amp, much like the receiving element of a conventional telephone.

When a disc recording of an IK tone is played back, the playback stylus will trace out the side to side swings in the groove. In the case of our IK tone, the stylus must repeat this side to side swing 1,000 times a second.

Since this IK tone was a sine wave, the stylus stops at each of its amplitude peaks and reverses its direction. It then picks up speed until it reaches peak velocity (at the point it crosses the groove centerline). It slows itself down again as it approaches the next amplitude peak in the sound wave. This process will keep repeating itself until the end of the record.

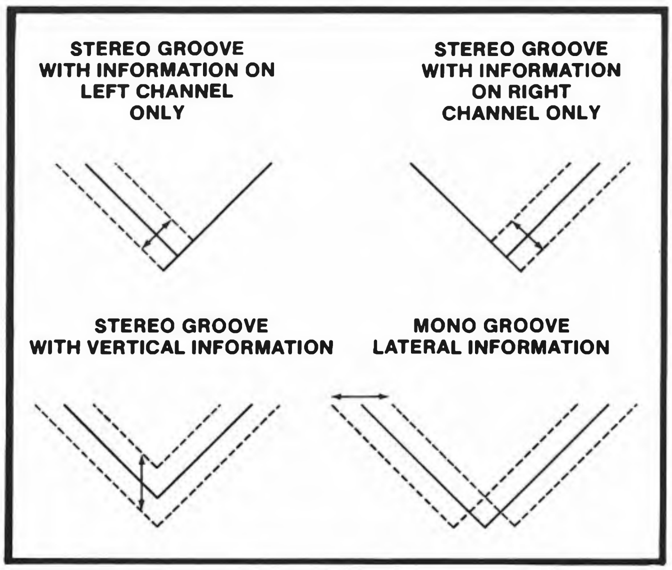


Technique A is the obvious way to cut two channels in a single groove. This method is extremely difficult.

Technique B is the Westrex System. Note that the left and right channels are still at a 90° angle to each other, but that the plane of modulation has been rotated to 45° to the horizontal surface.

Stereo happened when some very clever people found a way to use a combination of both side to side motion (called lateral) and up and down motion (called vertical). One channel would be cut in the vertical plane at the same time another would be cut in the lateral plane.

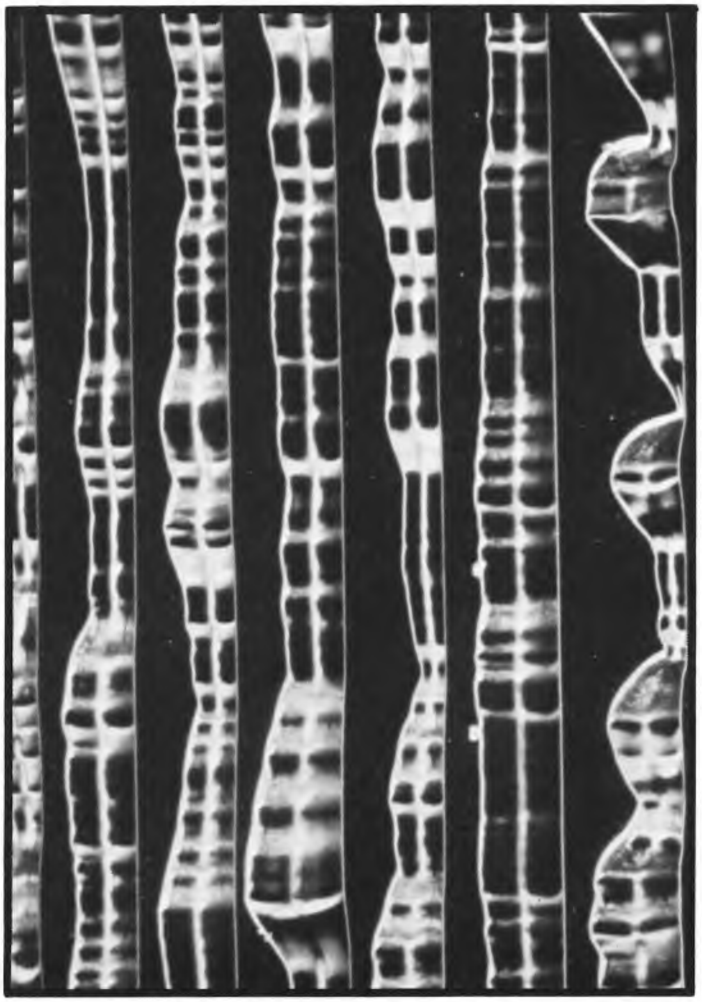
This kind of stereo worked, but had several big flaws. One of the biggest was compatibility with mono pickup cartridges. At this point, some more clever people known as the Westrex Company developed a technique called the 45/45 system that eliminated the flaws and is now the universally accepted method.



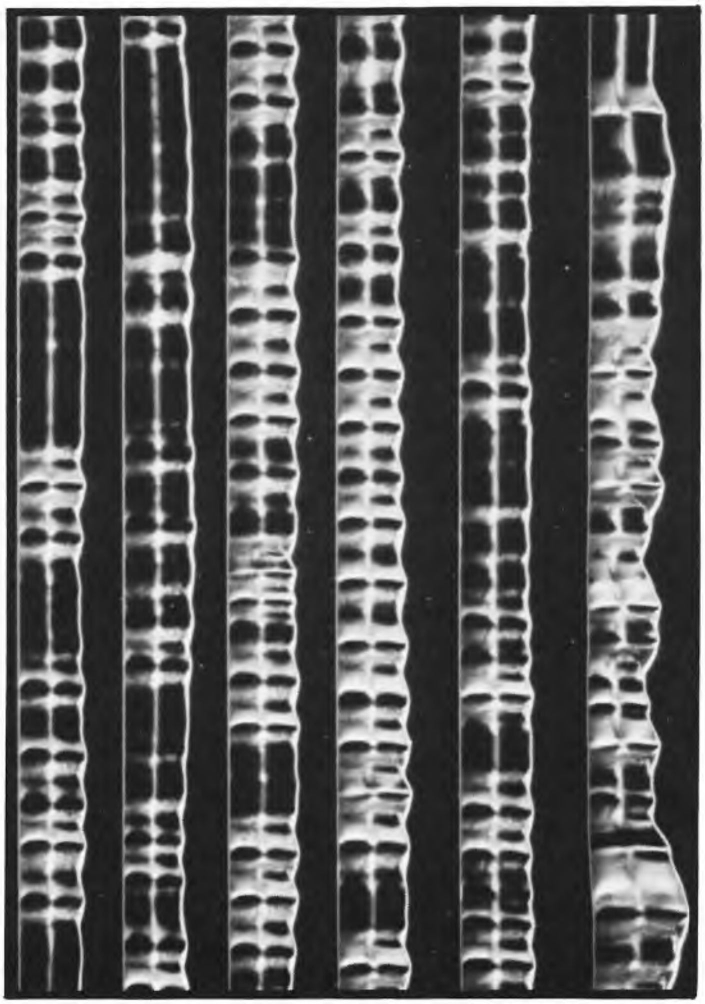
Westrex kept the 90° relationship of lateral to vertical but rotated the axis 45° to the plane of cut. This system made **physical** compatibility a reality. In addition, rumble is generally more pronounced in the vertical plane. The 45/45 system rumble is identical in both channels and lower by about 3 DB overall.

It is important to remember that it is varying groove width which causes the stylus to move up and down. Lateral stylus movement is caused by the wandering groove center. This is a fact of groove life, even if one groove wall has a different number of ripples or even if both channels are active at the same instant.

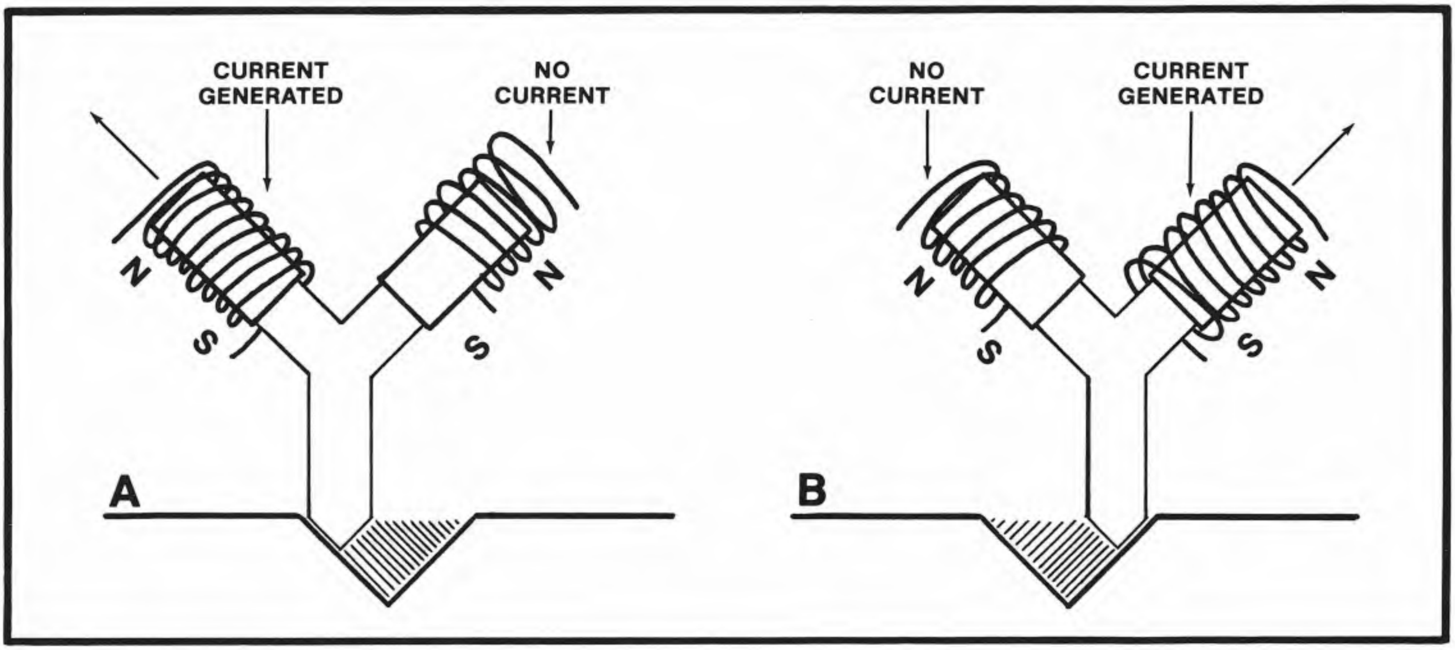
If the two halves of the stereo signal are mostly out of phase, the playback stylus will be driven in a vertical plane. If these same two halves are also of equal volume, the groove will get thinner and shallower, then deeper and wider. If one of the halves is louder than the other, the groove mid-point will move towards the side with the stronger signal.



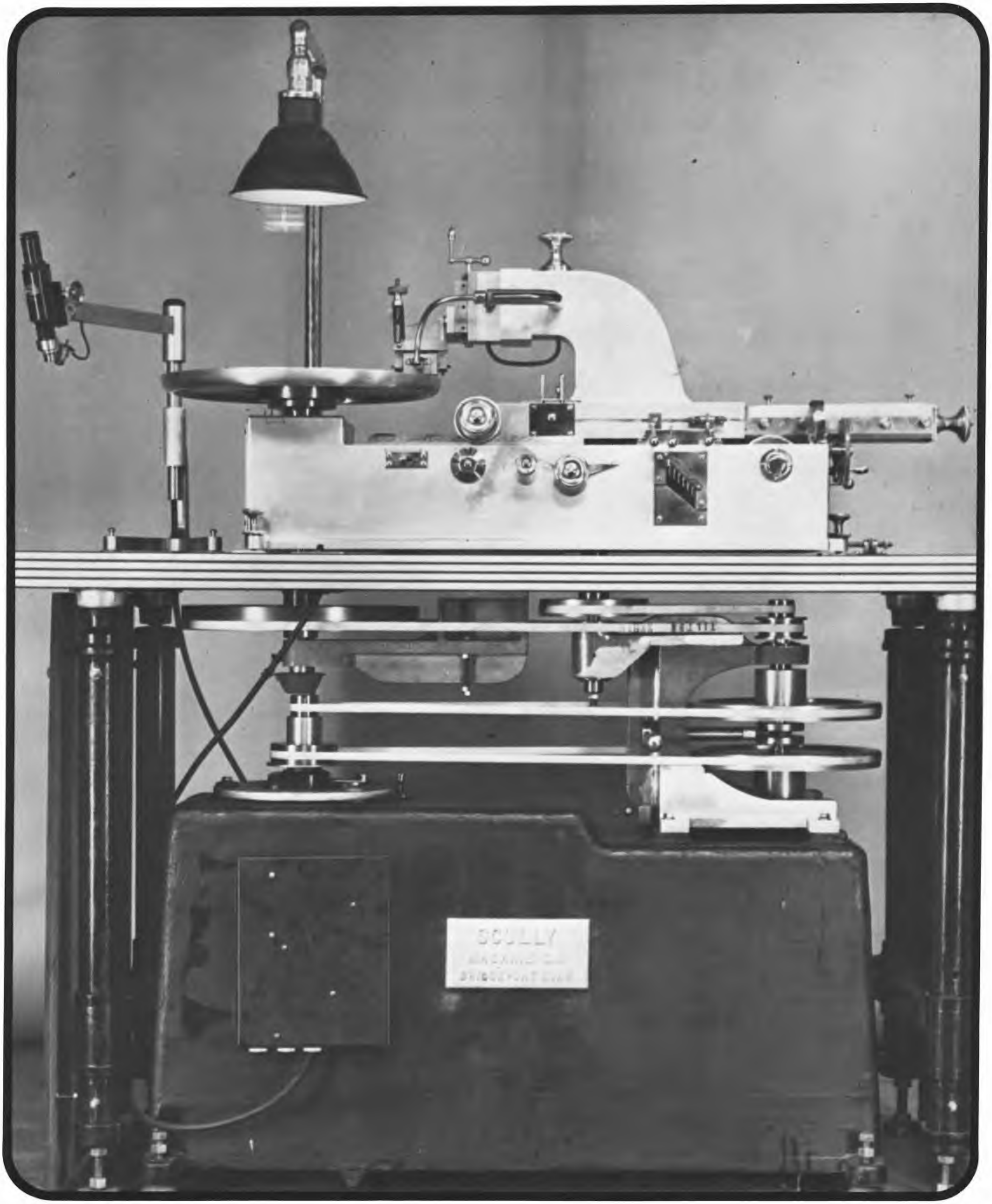
Picture of stereo grooves with information on left channel only.



Picture of stereo grooves with information on right channel only.



A playback stylus translates the stereo groove back into two distinct signals. "A" shows right channel output; "B" shows left channel output.



An old Scully Lathe, with covers removed to show the drive system. Over 600 were made. Many are still in use. (Manufacturer's photo)

The Cutting Lathe

"The Lathe" — current model of the L. J. Scully Company. A Westrex cutterhead is mounted in the carriage assembly. (Manufacturer's photo)

The main tool used in the mastering process is, of course, the cutting lathe itself. While many different brands are used, their function is the same, even while their form may not be.

A turntable is one of the main components of a cutting lathe. It is normally made of forged aluminum. Depending on the brand, the surface may be covered with cork. Basic to the turntable system is a vacuum mechanism which holds the blank master disc firmly in place to prevent any slippage of the disc while the cutterhead cuts into it. Such slippage would show up as a speed variation in the finished record.

The actual cutting of the groove is performed by the cutterhead. It is mounted on the lathe "carriage". The carriage travels across the disc by riding on a "leadscrew". The speed at which the carriage (including the cutterhead and the cutting stylus) travels across the recording blank is shown as the "pitch" of the lathe. Pitch is normally expressed in "lines per inch". A meter on the control portion of the lathe reads out the pitch in lines per inch. In common usage, the term LPI is used for lines per inch.

From the very beginning of disc recording until the late fifties, records were mastered at a "fixed" pitch. For example, a twenty-minute album side was cut at a continuous 225 LPI setting. This means that the lathe carriage cut 225 grooves per inch of space from the modulation start diameter (about 11.75") until the minimum inside diameter (4.75").

With the advent of stereo records and more demanding program material, some manufacturers devised a method of constantly changing a lathe's recording pitch, depending on the program material. In addition, units that would vary the depth of cut automatically were also introduced. Thus, the variable pitch-variable depth cutting lathe was born.

There are exactly 86.10469 square inches of recording space on a 12" long-playing record. All album sides, be they ten minutes or thirty minutes in length, must fit into this area. Naturally, the longer the running time, the finer "pitch" or more LPI we must cut.

A variable pitch and depth system permits us to make the economical use of our 86 inches by constantly sampling the program material and adjusting the pitch and depth of cut accordingly.

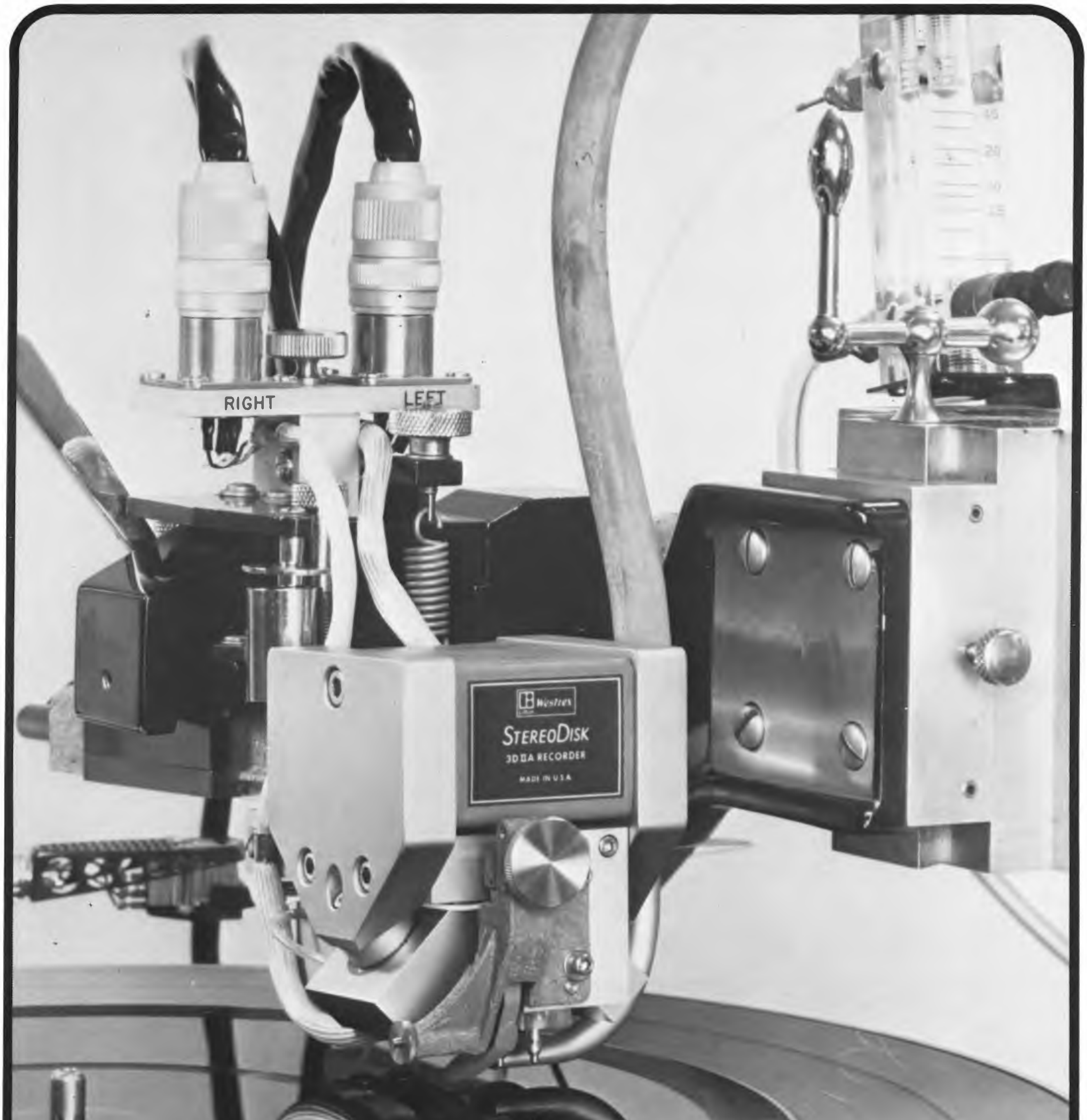
The job of the variable pitch unit is to stop the groove walls of adjacent grooves from banging into each other (the term for this is "overcut") while at the same time, keeping the pitch high enough to avoid wasting any of our 86 inches.

The job of the variable depth unit is to keep the groove width at at least one mil (the normal width of a playback stylus is .7 mil, so one mil is considered the minimum acceptable width) and also to keep the groove width less than about 6 or 7 mils. With grooves deeper than 7 mils, we run the risk of jamming our cutting stylus into the disc's aluminum substrate and ruining it or at the very least, cause problems in the record pressing process.

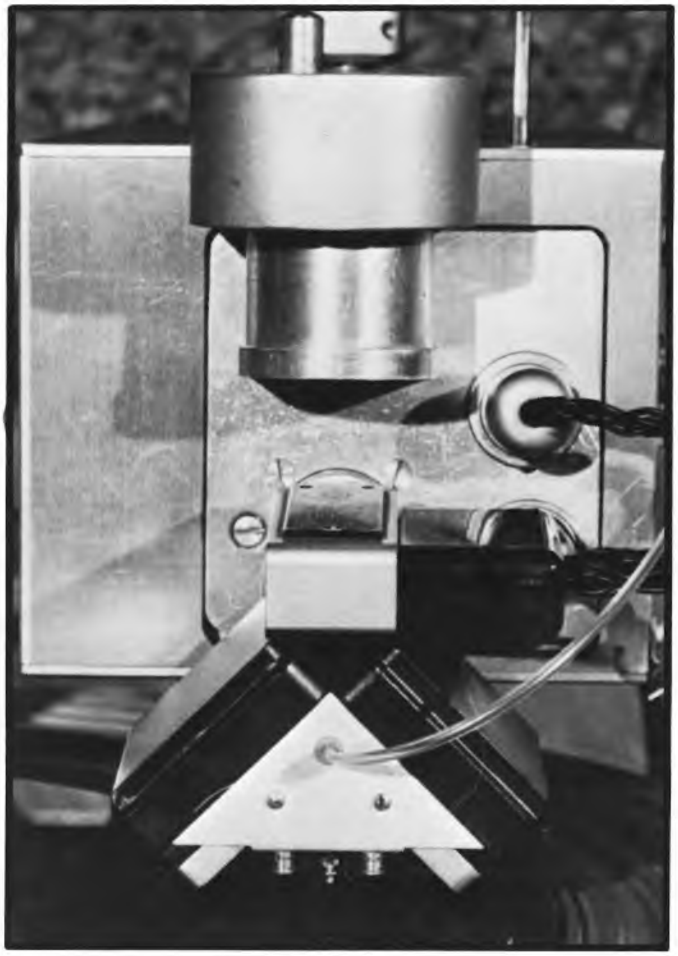
Although their functions are separate, the pitch and depth units are interlocked and work together hand in glove. For instance, increased groove depth

A Neumann VMS70 Cutting Lathe, the most common lathe found today.

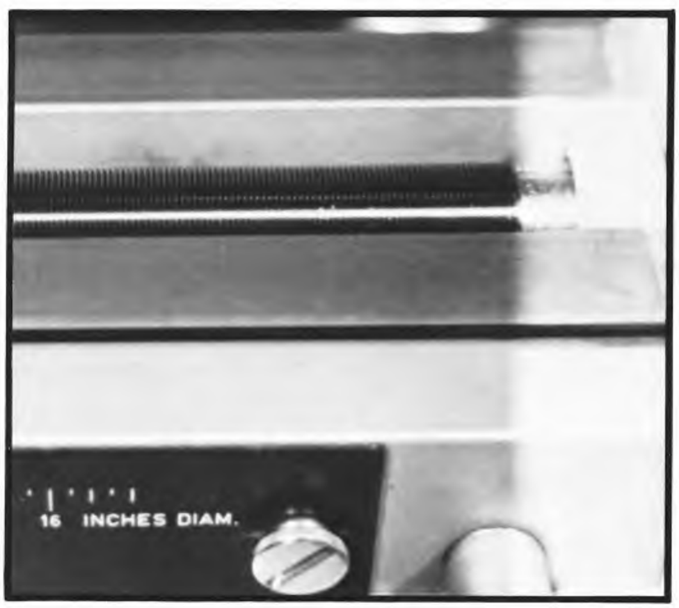
Close-up of the turntable of a Neumann Lathe, showing disc size selector and vacuum holes for disc hold-down.



The Wextrex 3DII AH Stereo Cutterhead. (Manufacturer's photo)

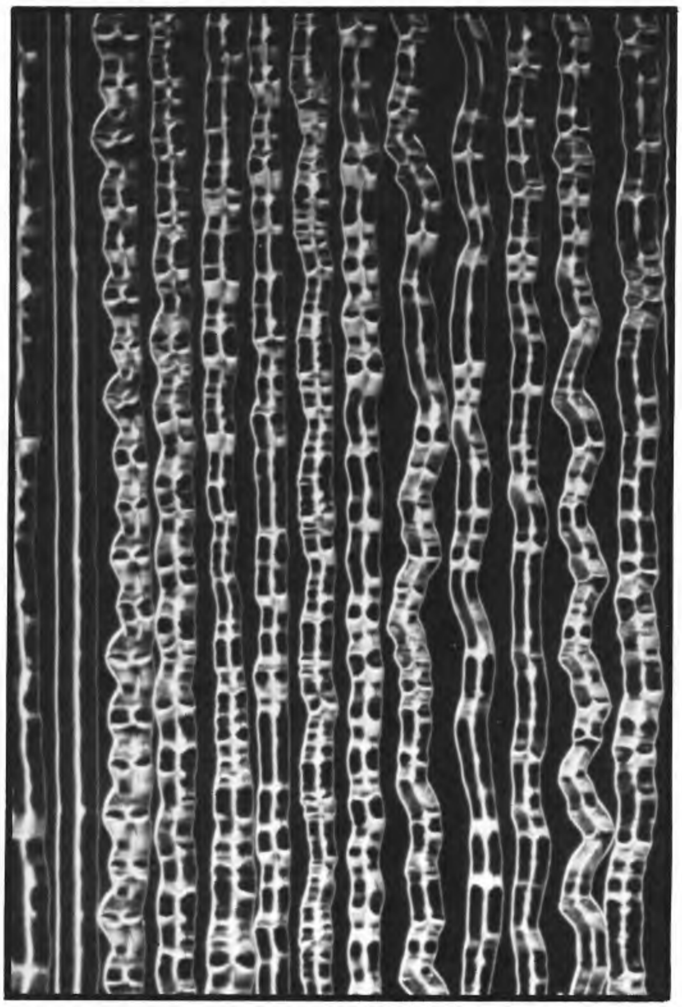


The Neumann SX-74 Stereo Cutterhead.

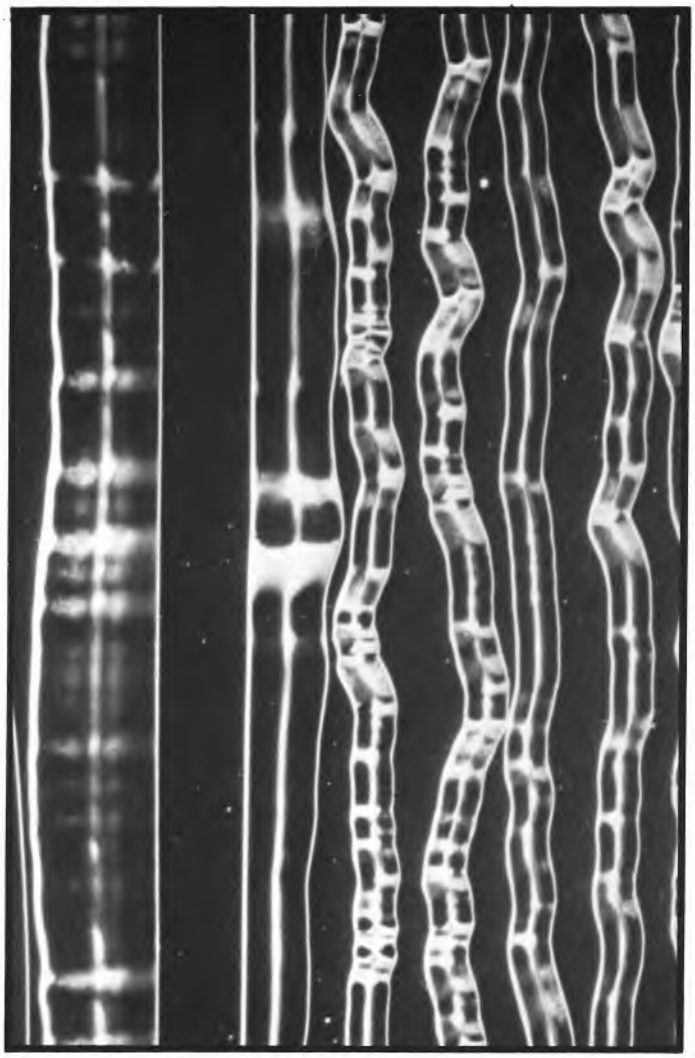


The lead screw of a Neumann Lathe. The carriage rides on this screw on its journey across the disc. The "pitch" is changed by speeding up or slowing down the motor which turns it.

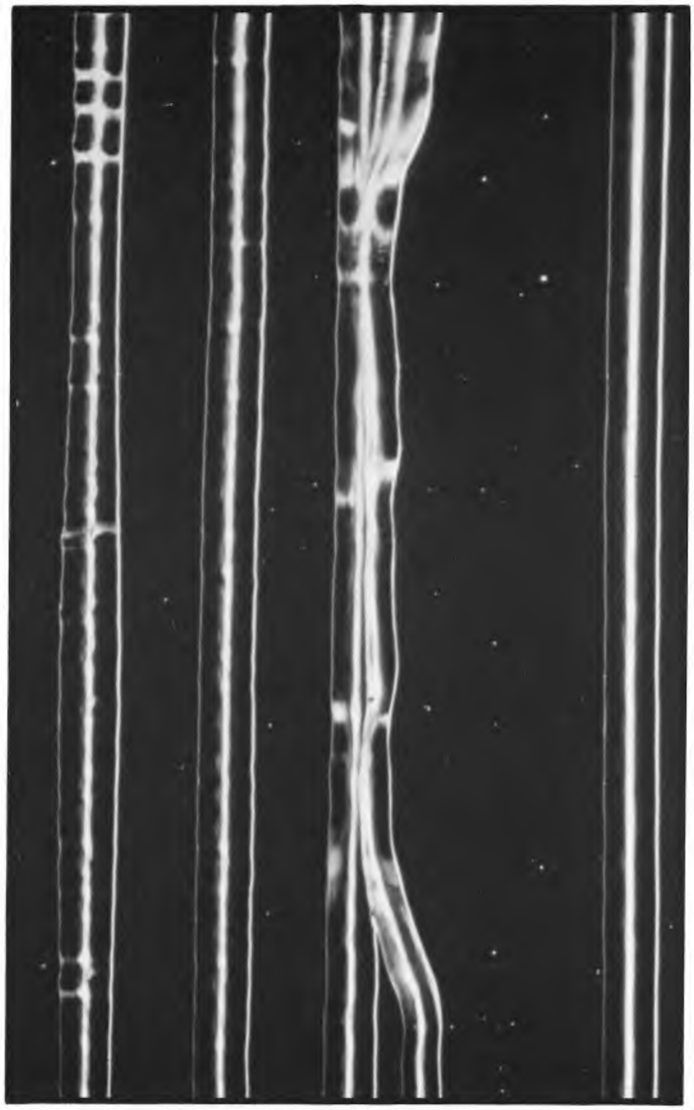
The LPI Meter shows our cutting pitch. Here, 130 L.P.I.



Variable pitch at work, controlling groove spacing to avoid overcut.



Variable depth at work, deepening the groove as needed. As the groove goes deeper, note that the pitch must be expanded to accommodate the depth increase.



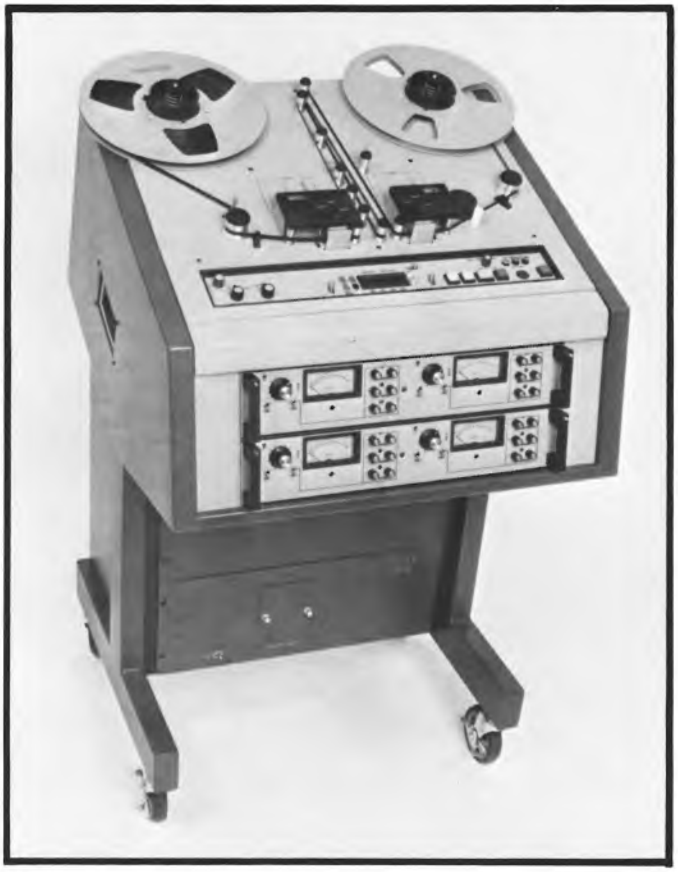
A severe overcut.

cuts down on the "land" (land is defined as the space between two grooves). The space used to allow this groove deepening is gained by cutting fewer lines per inch. Any increase in our LPI reading should be accompanied by a decrease in our depth of cut. Likewise, any increase in our depth of cut should go hand in hand with fewer lines per inch.

Since it is necessary for our pitch and depth units to have access to the recorded information ahead of its arrival at the cutting head, a special tape machine is used in the mastering process. This tape machine is equipped with two totally separate playback systems along with an elaborate tape threading path between these two systems. The first playback system is called the "advance" or "preview" channel. The second is called the "program" channel. With the help of an elongated tape path between the preview playback head and the program playback head, the operator can allow for a time lag between the variable pitch and depth units receiving a signal and the arrival of that same signal at the cutterhead. This lag time will vary with the speed of the master tape and the speed at which the master disc is being cut.

It is worth noting here that the signal sent to the pitch and depth units should correspond in both level and signal processing as the program channel. If the lathe operator were to compress or equalize the program channel without making like changes on the advance system, the pitch and depth units will be receiving false information which could cause overshoot or undershoot in their actions. For this reason, most lacquer channels have two duplicate sets of filters, equalizers, etc.

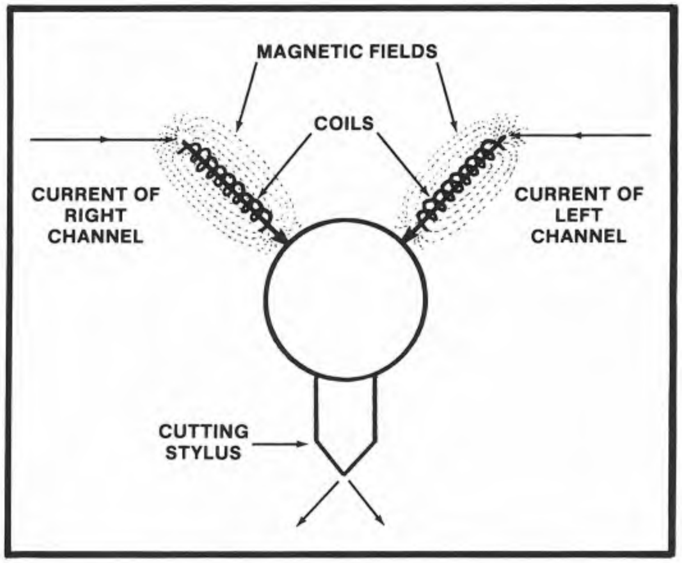
The different pitch and depth units in use today are often called "computers" of one sort or another. Some are very sophisticated. The pitch control is



A disc mastering tape playback unit manufactured by MCI. Note long delay path between program and preview heads. (Manufacturer's photo)

The Studer A-80 Preview Tape Machine.

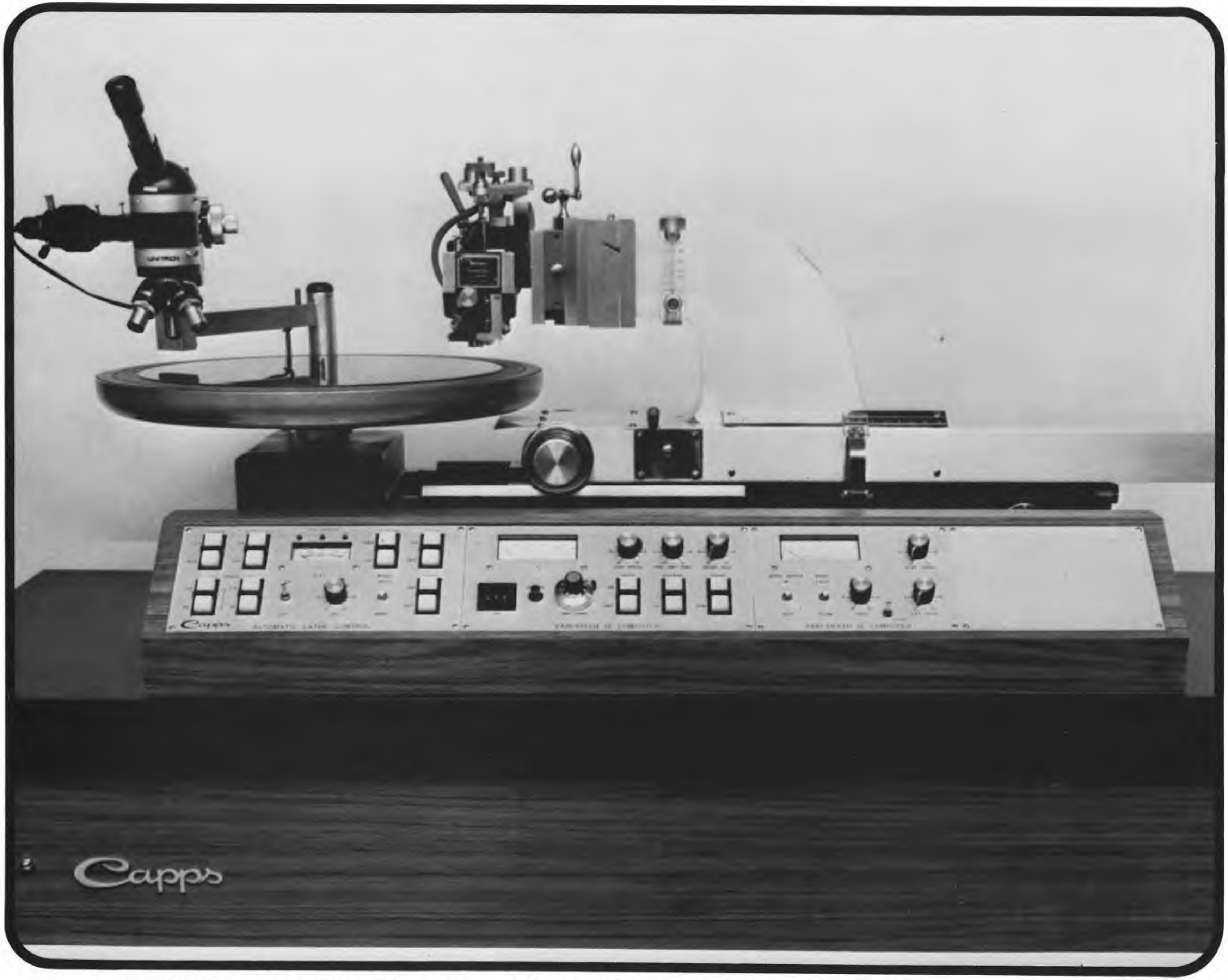
Control Section of a Neumann Lathe, showing turntable speed indicator, lathe function control and L.P.I. Meter.



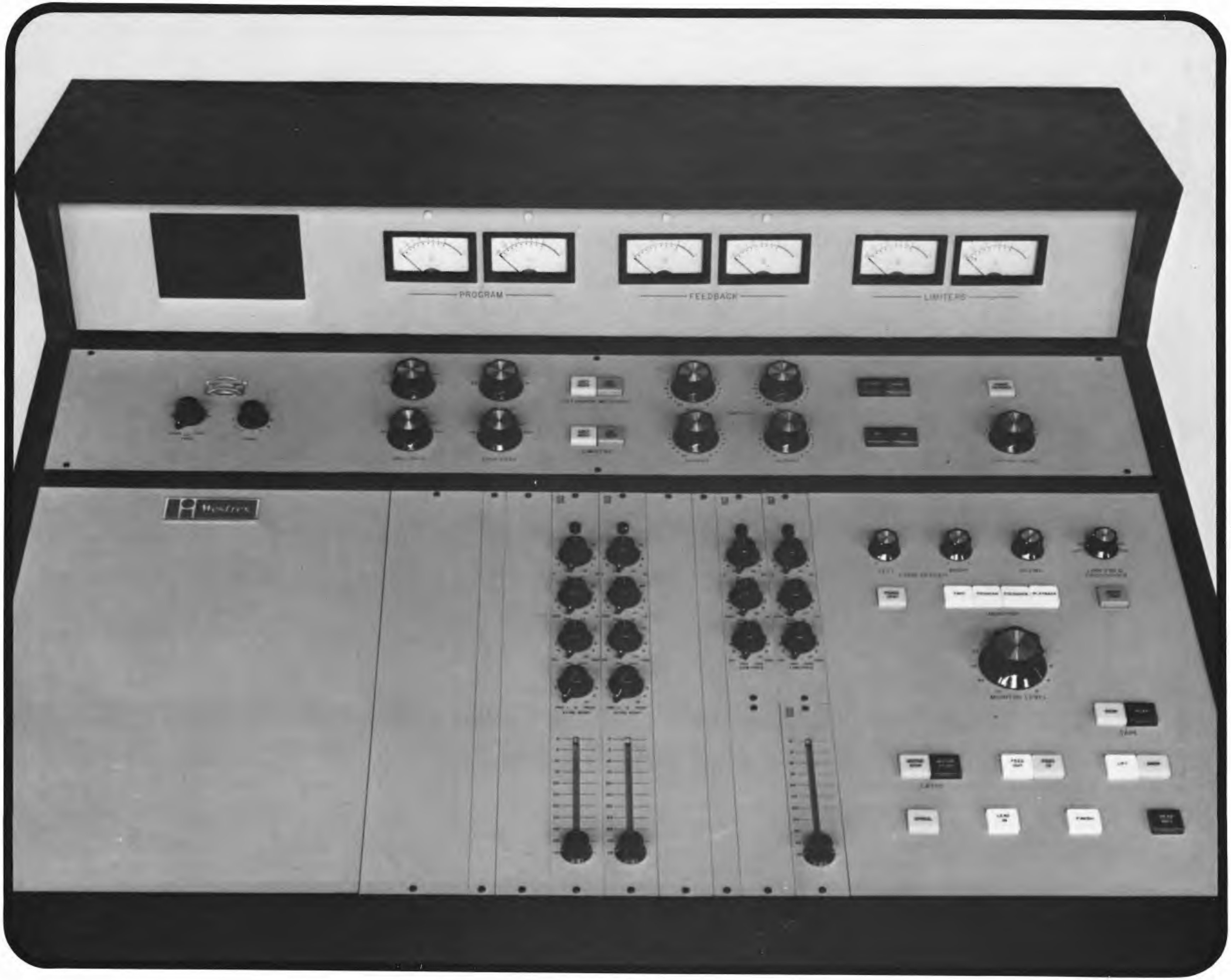
Simplified view of a stereo cutterhead.

mainly a function of the sum signal of the preview channel (left signal + right signal = sum). The depth control is mainly concerned with the difference signal (left signal - sight signal = difference). In any case, the various systems are mainly concerned with frequences below 1500 cycles. At the same input level, a 125HZ tone occupies 2.25 times the space that a IK tone would. At 30 HZ, the increase is four times.

The cutting lathe has many other controls and functions. Controls are located on the front for stylus heat adjustment, depth of cut, beginning and closing diameters, turntable speed and the size of the "spirals" or "bands" between cuts.



A Scully Lathe (same as on Page 6) but fitted with a new, highly sophisticated pitch and depth computer by the Capps Co. (Manufacturer's photo)



The Westrex Mastering Console. (Manufacturer's photo)

The Mastering Console

Although it has only four inputs, the mastering console can be very complex and contain many items not found in live sound recording consoles.

Normal functions included on most mastering consoles are:

(1) **Mono/Stereo Switch** — This allows the engineer to cut a mono disc from a stereo tape.

(2) **A Master Fader** — With this tool, the cutter can fade out a selection earlier, at times an improvement if the original fade was too long or too abrupt.

(3) **Level Controls** — These allow the engineer to control the volume going to the disc.

(4) **A Phase Reversal Switch** — This flops the phase of the stereo signal 180°. Used as a corrective measure when a tape is encountered that is also 180° out of phase.

(5) **A Monitor Select Section** — With this, the cutting engineer can listen to the signal at any stage of its route through the system.

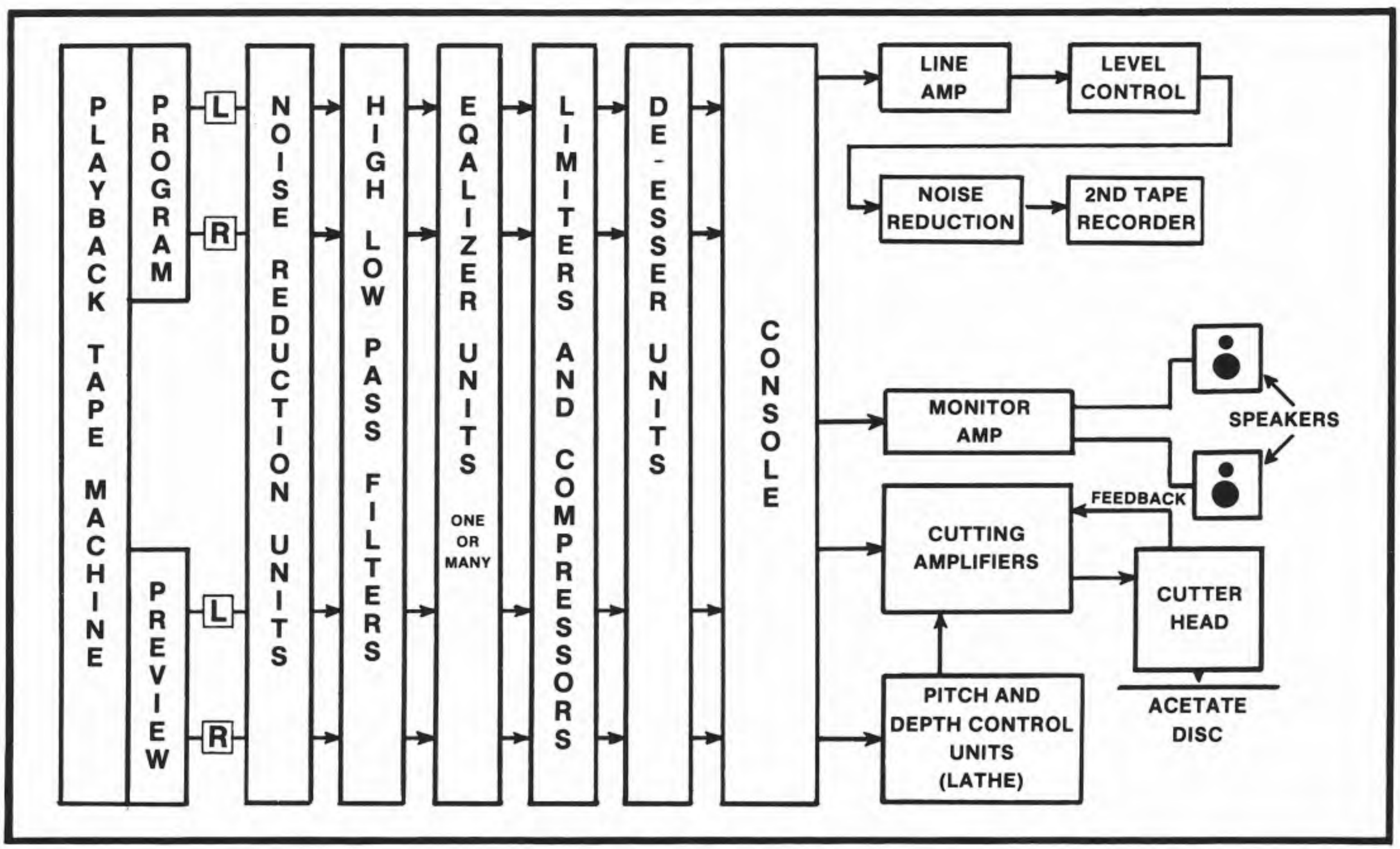
(6) **Echo Send and Return** — Same function as in recording consoles.

(7) **Low Frequency Crossover** — Requires a detailed explanation and has its own section of this book.

(8) **Outputs to Outboard Tape Recorders** For making tape copies simultaneously with mastering. These copies contain all the limiting EQ, echo, etc., as the master. These copies can then be shipped to foreign countries or to a tape duplicating facility. The record will then sound uniform from country to country and from the record to the cassette.

(9) **Oscillator** — Used for putting tones on the above tapes or for testing purposes with the cutting system.

(10) **An Oscilloscope and/or a Phase Correlation Meter** — Discussed elsewhere in this book.



Simplified Flow Chart of a typical mastering chain.

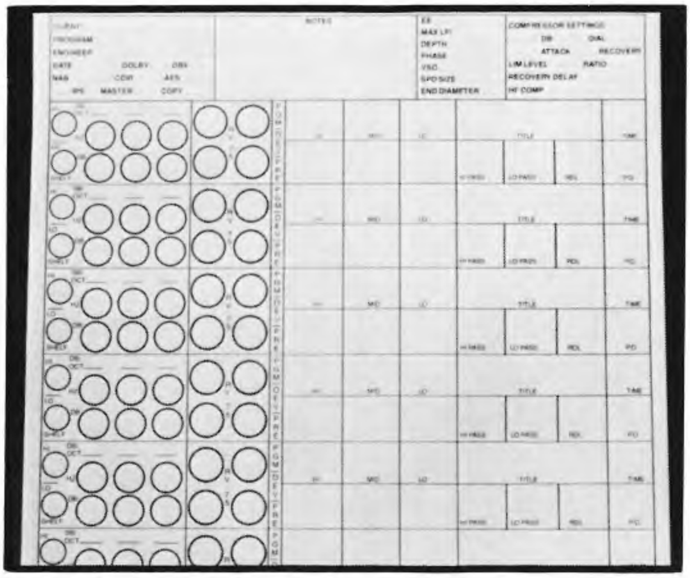
A Neve Mastering Console. (Manufacturer's photo)

(11) **Compressors and Limiters** — Same function as in live recording.

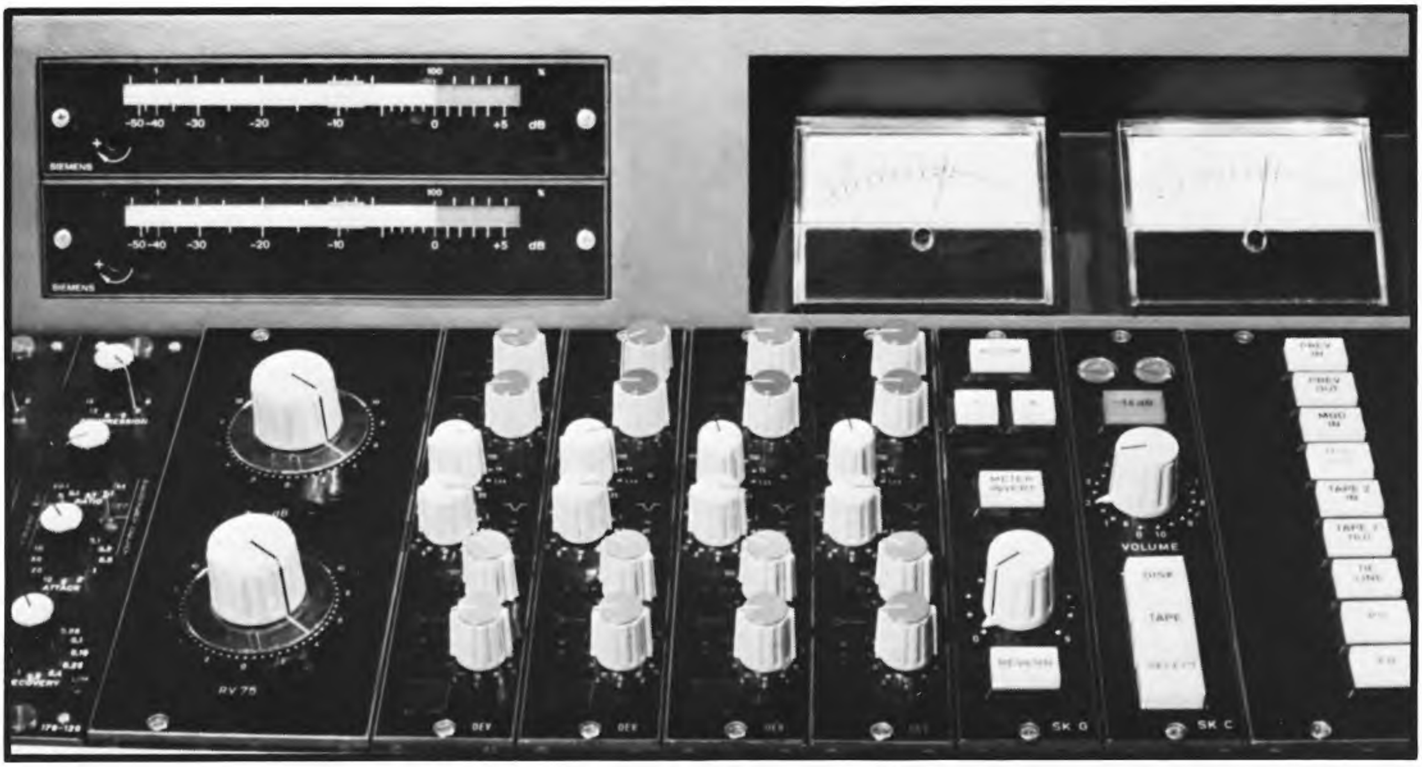
(12) **Several sets of Equalizers** — Most modern mastering consoles are arranged in an "A-B" fashion. The engineer can reroute the signal through different sets of level controls and equalizers between selections. An engineer can then "pre-set" the level and EQ for the following selection. He can then switch from the "A" routing to the "B" routing inaudibly during the spiral on the record. The console can be made to do this routing on its own by means of a light cell on the tape machine which "sees" the leader tape and sends a signal to the routing change mechanism. This feature gives tremendous artistic leeway to the cutter.

(13) **Full Metering for Level** — Every DB counts in the mastering room. In addition to normal VU meters, one or several sets of peak reading meters are also used. While the studio control room line level is 0 DBM (0.775V) the counterpart in the disc field is 1.55V (+6 DB over 0-DBM). This level is used to adjust the full scale deflection of the peak reading meters. O VU corresponds to -6 DB on the peak scale or 0 DBM in disc cutting lingo.

One factor that is foremost in the set-up of a mastering console is ease and exactness of repeating settings. Oftentimes an engineer is called on to cut lacquers identical in level and signal processing to others he cut months or even years ago. When cutting each disc, the engineer keeps copious notes and meticulously records the settings of each equalizer, echo unit, etc., with this idea in mind. Most studios have preprinted forms of some sort matched to their equipment. Lathe settings are also recorded as are the ending diameter and size of the bands between selections.



Typical mastering setting sheet, allowing the engineer to repeat his settings at a later date.



Both peak and VU metering are handy in disc cutting.

The output of the Mastering Console is fed into the cutting amplifiers, which in turn drive the cutterhead.

The Low Frequency Crossover

Sometimes called an elliptical equalizer, the low frequency crossover is a universal tool of all cutting studios. It is normally abbreviated as 'LFX" or "EE".

Should there be program material on the master tape that is low in frequency and also more than 90° but less than 270° phase difference, the LFX will be used to eliminate excessive vertical groove lifts. This lift complicates both the pressing and the playback operations.

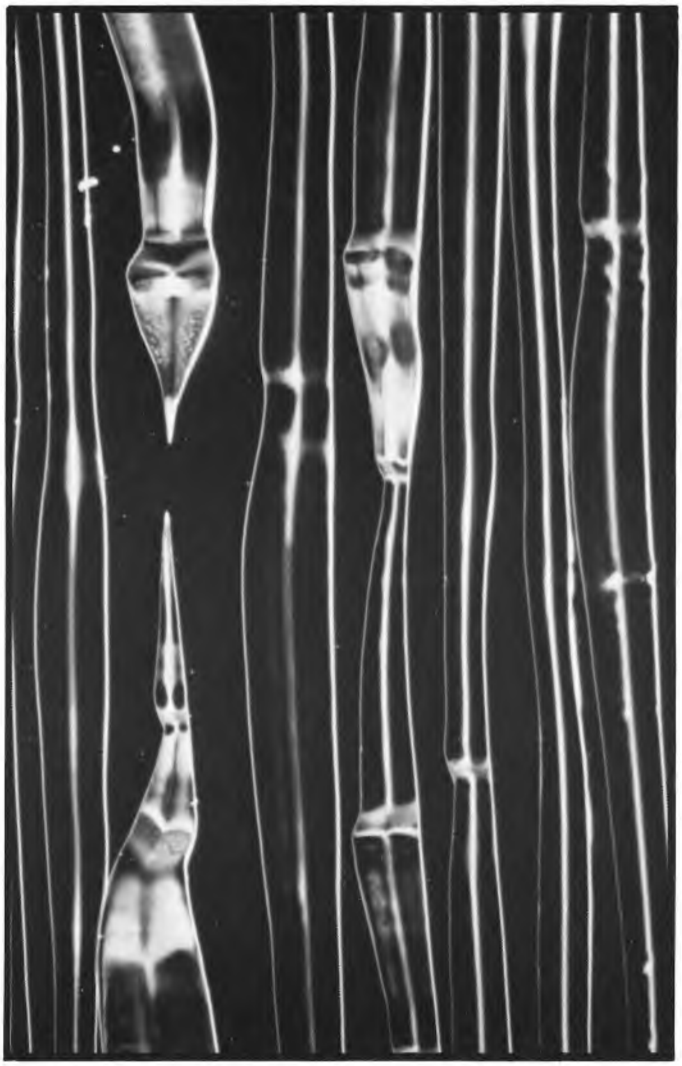
If the recording level of these identical signals were the same and they were 180° out of phase, the groove would be entirely vertical (hill and dale) in the normal 45/45 method of mastering. The LFX can be set to work at various frequencies to allow a tolerable cut.

While disc cutters prefer to keep separation at its absolute maximum, there will be times when there will be sufficient out of phase material to make disc transfer troublesome.

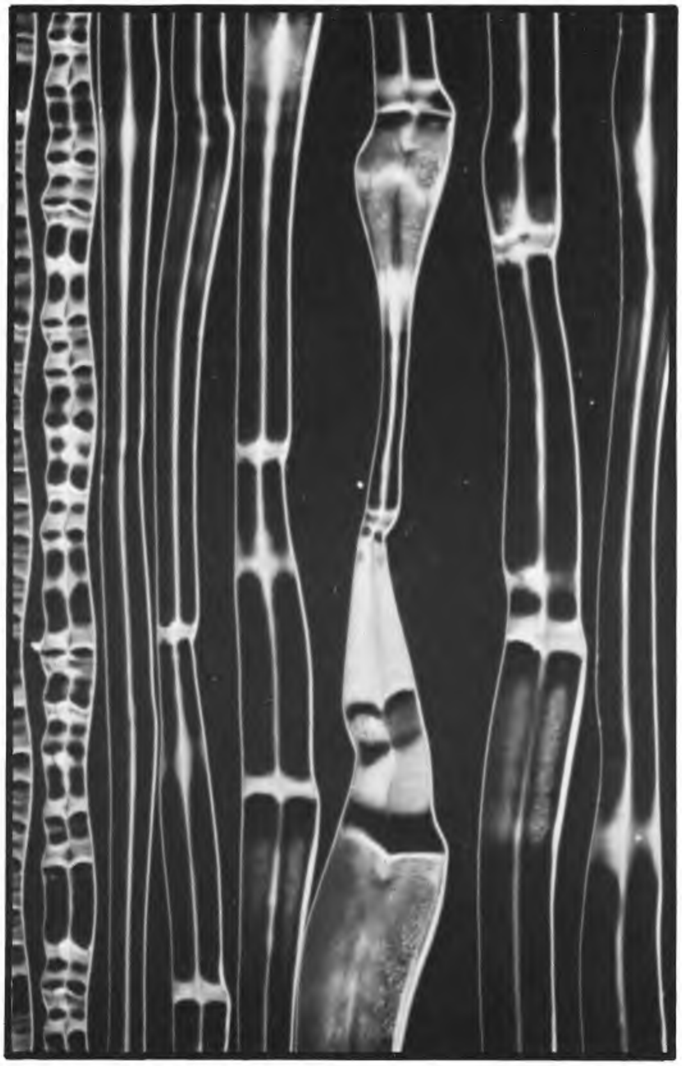
Basically, the low frequency crossover works by allowing the stronger of the out of phase components to cancel the portion of the weaker likeness on the opposite channel. That channel will then double terminate or leave half of its remaining power in place of the original out of phase likeness.

There are times when too much crossover will alter the overall sound to an objectionable degree. Prudent use of this device is a must.

Typical frequencies might include 30, 70, 250 and 700 cycles.



Out of phase material can make a cutterhead "lift out," thereby breaking the groove. The lift out shown here is unacceptable.



This photo is the identical section but cut with the aid of a low frequency crossover.

Oscilloscope

No mastering studio is complete without an oscilloscope permanently mounted in its cutting system.

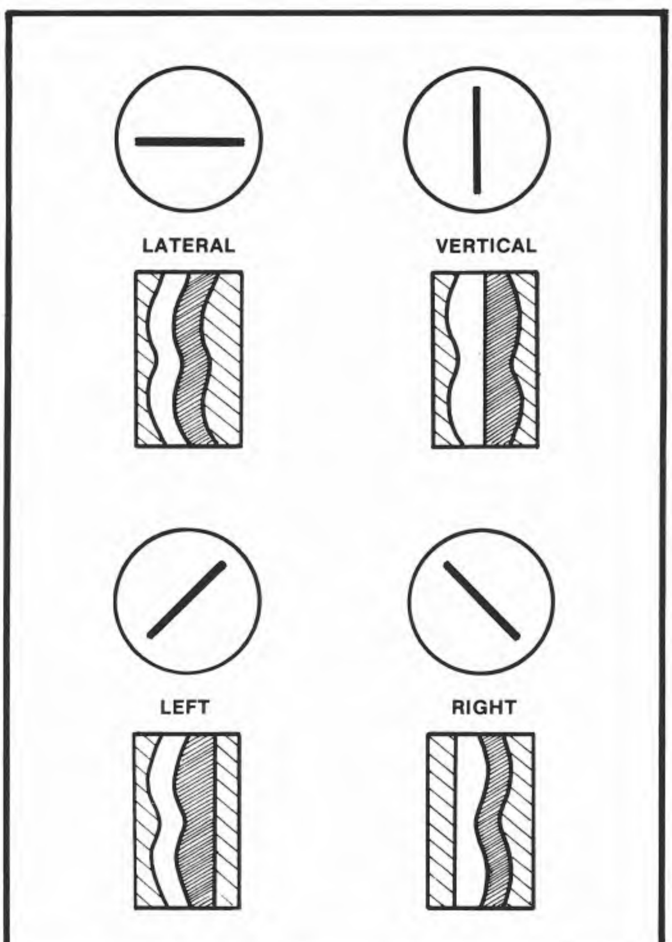
Since phasing is so important in producing a good lacquer master, this oscilloscope will be set up to read a "Lissajou" pattern. Basically, an X+Y superimposing of both the left and right signals.

An experienced cutting engineer can tell several things about a tape with his oscilloscope:

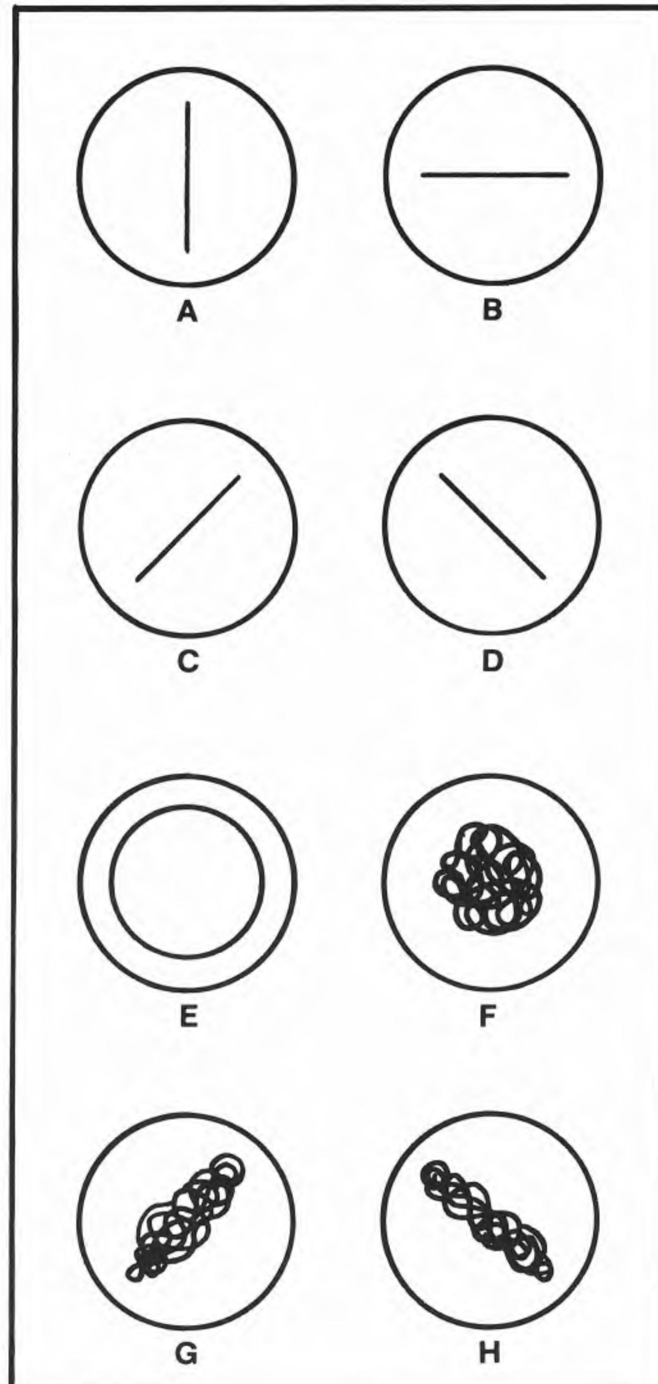
1. Whether the tape is stereo or mono
2. The amount of stereo information
3. Degree of out of phase components

Sometimes only one microphone or channel will have a phase problem. With careful observation, the component can be identified.

Another major use of the oscilloscope is the alignment of the playback tape machine's azimuth with the tone of the individual master tape being used.



Oscilloscope patterns with matching groove types.



Common oscilloscope patterns. A. Left channel only; B. Right channel only; C. Stereo, a combination of A and B; D. Stereo as C, but 180° out of phase; E. Phase shift of 90°, seen when aligning azimuth of playback tape machine; F. Random stereo, such as might be seen on a multi-miked recording. Some out of phase material present; G. Stereo program which is largely in phase; H. Stereo program which is largely out of phase.

Microscope

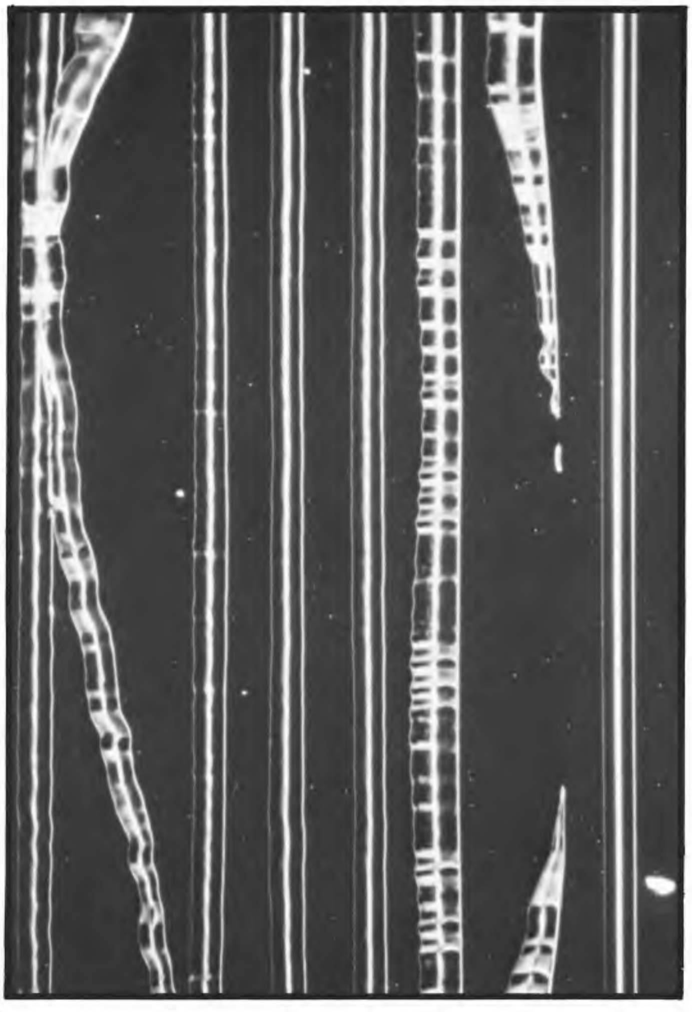
An indispensible tool of the mastering engineer is his lathe microscope. Most microscopes so used have a magnification power of about 200. The microscope has its own light source built in, in order to illuminate the grooves on the dark disc surface.

Each groove appears as three bright lines — the bottom of the groove and tne tops of the two groove walls. The land between the grooves appears black. The groove walls themselves reflect various amounts of light.

By means of a reticle in the microscope, the size of each groove can be easily measured. Also, too much treble or bass or excessive level are easily identified.

The cutting engineer can also check the effectiveness of stylus heating and the overall condition of the stylus by examining the groove walls for rough texture or other anomalies.

Each disc is spot-checked through the microscope after cutting.



Overcuts, lift-outs and proper groove depth can be seen through the microscope.

A second, smaller microscope is used to mount the cutting stylus in the cutterhead.

The Lacquer Disc

It has been said more than once that the lacquer acetate disc is the heart of the entire record manufacturing industry. Indeed, this is the case. This one product is the first step in the manufacture of any record anywhere in the world.

If one were to ask a mastering engineer what one product does he watch the closest for flaws, defects and performance quality, he would tell you the master lacquer disc.

The physical makeup of such a disc seems quite simple: a thin coating of lacquer on a flat aluminum substrate, punch a hole in the center, presto.

Such is not the case. The formulation of the lacquer, the mirror-smooth finish of the aluminum center, plus the entire coating, drying and packing operations call for uncompromising skill and quality control.

Before the advent of the lacquer disc, masters were cut into large cakes of wax. While this worked rather well, it was cumbersome and downright awkward. The wax discs were breakable, subject to damage by heat and precarious to ship to the pressing plant.

A French company called Pyral was the first to coat nitrocellulose lacquer onto aluminum in the 1930's. Bill Speed obtained a license for the United States and started a company called Audio Devices. In 1937, acetate discs became the norm in recording studios. Wax disappeared rather quickly once the advantages of acetates caught on.

Aluminum was increasingly difficult to obtain during World War II. Glass was substituted for disc centers till the end of the War. Glass-coated discs cut very well, but were subject to breakage.

Today, three companies are involved in disc manufacture: Transco Products, Capital Magnetics and Pyral.

Upon receiving the aluminum centers from Alcoa, the surface of each disc is treated to remove any debris and also to allow for better lacquer adhesion.

Meanwhile, cellulose nitrate is prepared for coating. By itself, it decomposes readily.

Basically, there are four ingredients which help the cellulose nitrate in its job:

1. Resins — These improve adhesion to the aluminum substrate. In addition, they greatly affect the drying process.
2. Pigments — These aid in opaqueness and light reflective properties, thus aiding visual inspection of the finished disc.
3. Plasticizers — Add elasticity and overall softness.
4. Solvents — Help blend everything together into a harmonious mixture.

After the discs are coated, the drying process begins. This is done in a controlled atmosphere with control over humidity, dust and pressure. The master lacquers are then visually inspected. Only one side of each disc is given to be flawless. Then boxed, they are on their way to the cutting studio.

The waste acetate that is cut out of the groove is called "chip". By means of a vacuum system, it is sucked into a receptable for disposal.

The Cutting Stylus

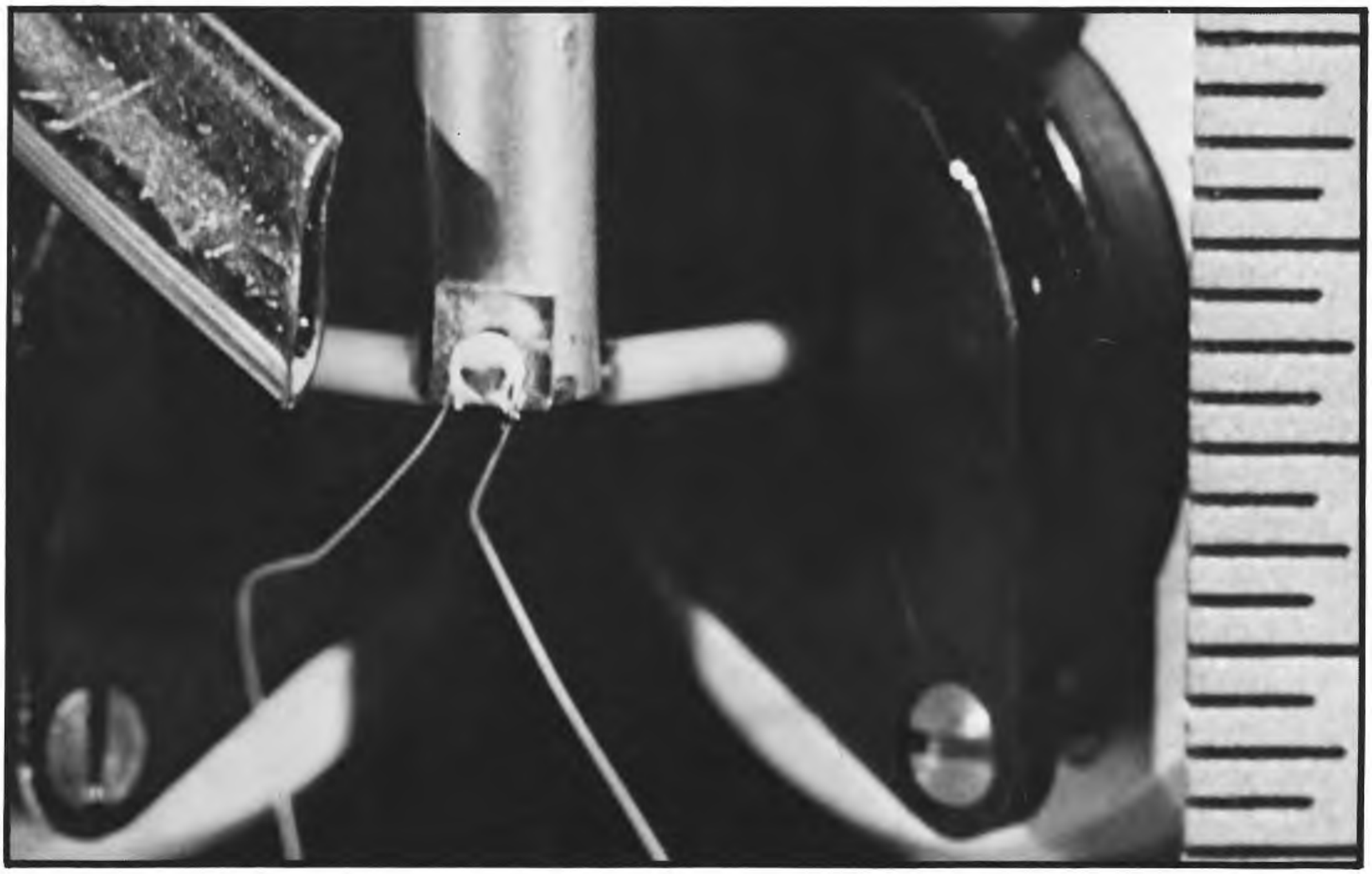
Another invaluable partner in the disc cutting process is the actual cutting stylus. Today, most styli are made from a synthetic sapphire compound, made from an aluminum oxide crystal. Since the center of the recording blank is also made of aluminum, the stylus has a certain affinity to other aluminum. Should the groove ever go deep enough to the point which it hits the aluminum substrate of the disc, some aluminum will adhere to the stylus. It is almost impossible to remove this adhesion from the styli. A stylus is never touched with bare fingers but is handled by means of the heating wires. Also, non-magnetic tweezers are used.

A finished master disc has a dynamic range about 15 to 20DB better than the pressed record made from it. Indeed, a master disc may tax the threshold of all but the finest preamps. The reason for this is twofold — stylus heat and stylus burnishing action.

The stylus is made blunt on each edge to form what are called burnishing facets. These facets are flared out a few degrees from the direction of travel so that they have a wiping or burnishing action on the just cut groove. If these facets are too wide, the life of the stylus will improve but high frequency response will be poor, since the stylus will cut, then immediately wipe away high frequency modulation. Conversely, facets that are too small will cause just the opposite to happen. Normally, the width of the burnishing facets range from .00015 to .0002 inches.

Styli are supplied to the cutting studio with nichrome wire wound around the shank and held in place by ceramic cement. These wires carry heater current to the stylus. The exact amount of heat is adjusted by means of a rheostat on the lathe. The amount of current is visible on a meter, also located on the lathe. During very critical work, the amount of heat is sometimes increased towards the center of the disc, due to slower groove speed.

The heat setting is checked with each new stylus or new batch of acetates. Heat is set to the amount that will produce the lowest hiss in a quiet groove. This is normally done at the inner and outer diameter, with an average setting the result.



The cutting stylus mounted in the cutterhead. Note chip removal tube at left and the two heating wires.

By means of the lathe microscope, heat can also be checked by eye. Too much heat produces scoring lines on the groove wall. Too little heat causes the groove wall to become gray and grainy in appearance.

The benefits of stylus heat are:

1. A reduced noise level
2. Prolonged stylus life
3. Improved high frequency response

A cutting stylus does an enormous amount of work, etching a groove up to a half-mile in length on one side on an LP. Although the recording lacquer is relatively soft and the stylus face highly polished, there is some abrasive action which causes wear on the stylus. The rate of wear will vary depending on the abrasiveness on the recording blank and the amount of discrete hard particles in the lacquer itself.

As the chip is forced out of the groove and slides up the face of the stylus, particles of the chip and the lacquer solvent adhere to the face. Since the tip is heated, this debris tends to bake on and form a rough crust which is difficult to remove.

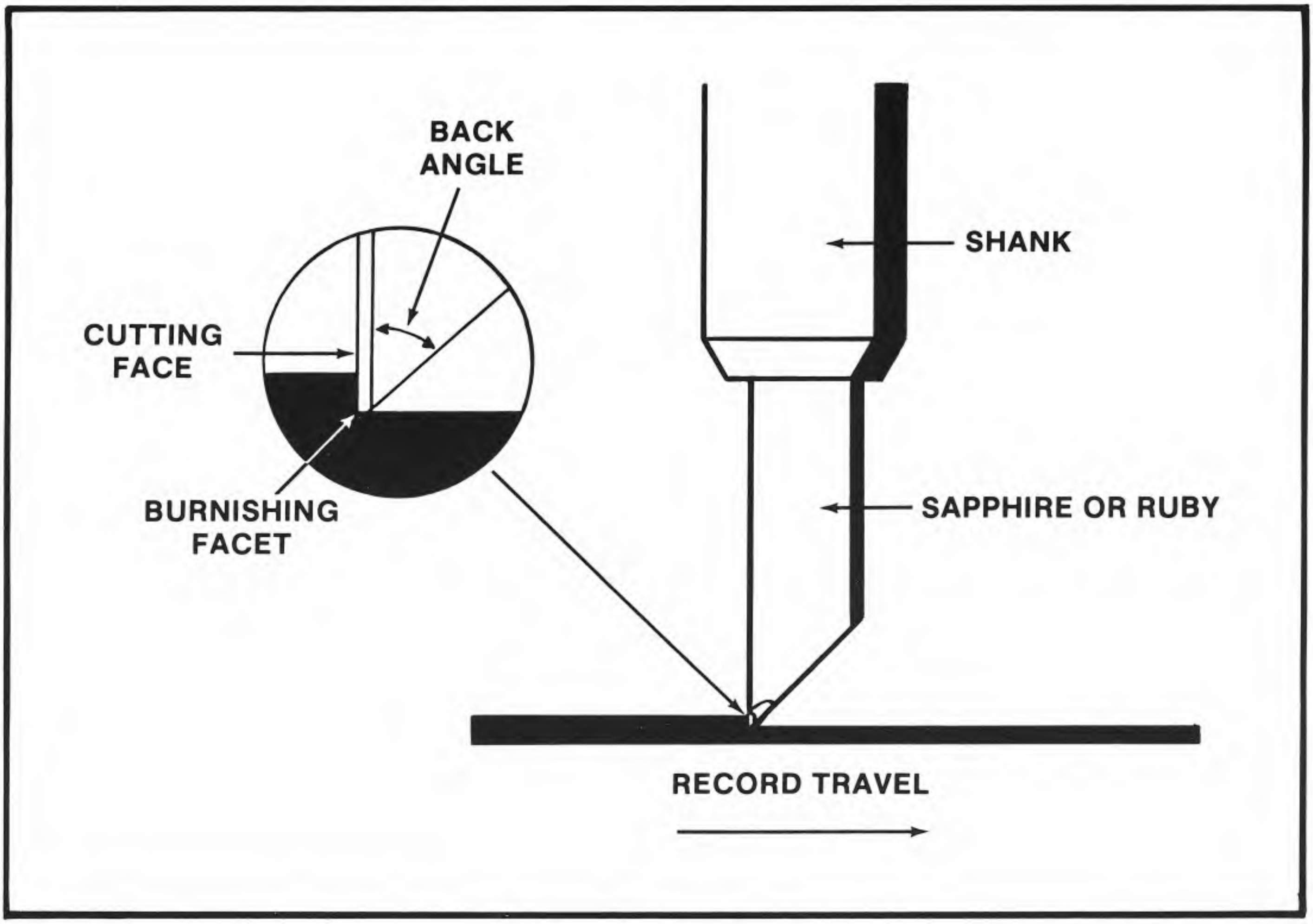
As this continues, this crust will creep lower and lower. Eventually, it gets in the way of the exiting chip and causes a kind of back pressure at the edge of the stylus. The noise level will rise to intolerable levels and the stylus must be replaced.

Styli are replaced for a variety of reasons:

1. When the cut is no longer shiny and smooth
2. When it becomes chipped
3. When the noise level is too great
4. When high frequency response falls off
5. When the tip radius exceeds .25 mils or the bottom line exceeds .5 mils

Generally, wear will show up on the edges after ten hours of cutting and the tip radius will be too large after about twenty hours.

Although some work has been done with making styli out of diamond, synthetic ruby and sapphire remain the jewels of choice, due to their ease in forming and absolute control of the grain. The latter is most vital in assuring good chip removal.



Enlarged view of stylus tip.

Common Disc Mastering Formulas

Now, as in the beginning, disc mastering is pure and unadulterated physics. As such, much mathematical material is available to the cutting engineer to help him set his working parameters. A few are given here.

The running time of the master tape determines the pitch of the cutting lathe. It follows, then, that the longer the running time of the tape, the more lines per inch must be cut to accommodate the material. Shorter sides, then, can be cut with fewer lines per inch.

One common formula for this is:

$$\frac{\text{Radius X Lines Per Inch}}{\text{DISC SPEED}} = \text{RUNNING TIME}$$

In this case the radius is the distance from the modulation start to modulation end. For an album, this is three inches. Let's see what running time we can get while cutting 300 lines per inch:

$$\frac{3 \text{ X } 300}{33.3} = \frac{900}{33.3} = 27.027$$

Therefore, we can cut 27 minutes of material if we adjust the lathe pitch to 300 LPI (lines per inch).

Another way to figure this is:

$$\text{Pitch} = \frac{\text{Running Time X Disc Speed}}{\text{Radius}}$$

Let's try this for an album side running 16:45. Before using any formula, all excess seconds over a whole minute must be converted to its decimal equivalent.

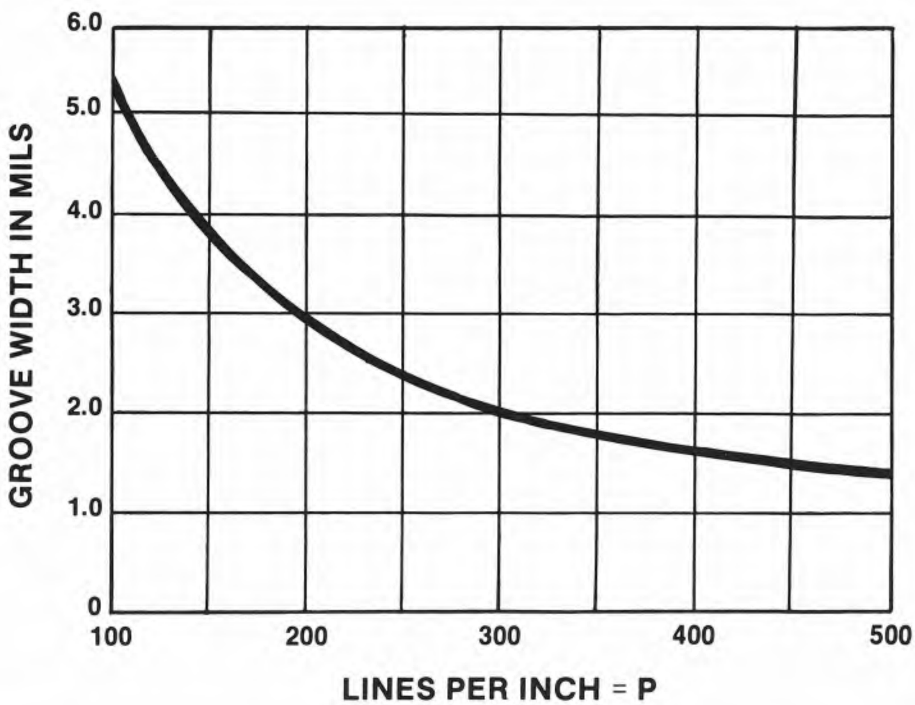
$$\text{Pitch} = \frac{16.75 \text{ X } 33.3}{3 \text{ inches}}$$

So,

$$\text{Pitch} = \frac{557.775}{3}$$

Then,

$$\text{Pitch} = 185.925 \text{ Lines Per Inch}$$



Groove width versus lines per inch. Average groove width $= \dfrac{\frac{1000}{P} + 1}{2}$

The line spacing is

$$\frac{1}{185.925} \text{ or } .0053785 \text{ Inches Per Line.}$$

Another common formula is used to figure the appropriate groove width for a given LPI setting:

$$\text{Groove width} = \frac{\frac{1000}{\text{LPI}} + 1}{2}$$

Let's solve this formula for a 250 LPI setting

$$\text{Groove width} = \frac{\frac{1000}{250} + 1}{2}$$

So,

$$\text{Groove width} = \frac{4 + 1}{2}$$

Then,

$$\text{Groove width} = \frac{5}{2} \text{ or } 2.5 \text{ mils}$$

The stylus velocity is directly proportional to the electrical signal applied to it. The displacement of the groove, however, is inversely proportional to the frequency of the signal. As we decrease this frequency, this displacement increases. (Remember, heavy bass takes up a lot of space on the record.) The formula for figuring this displacement is:

$$\text{Amplitude Of Displacement} = \frac{\text{Peak Stylus Velocity}}{\text{Angular Frequency}}$$

Angular Frequency is 2π X the Frequency

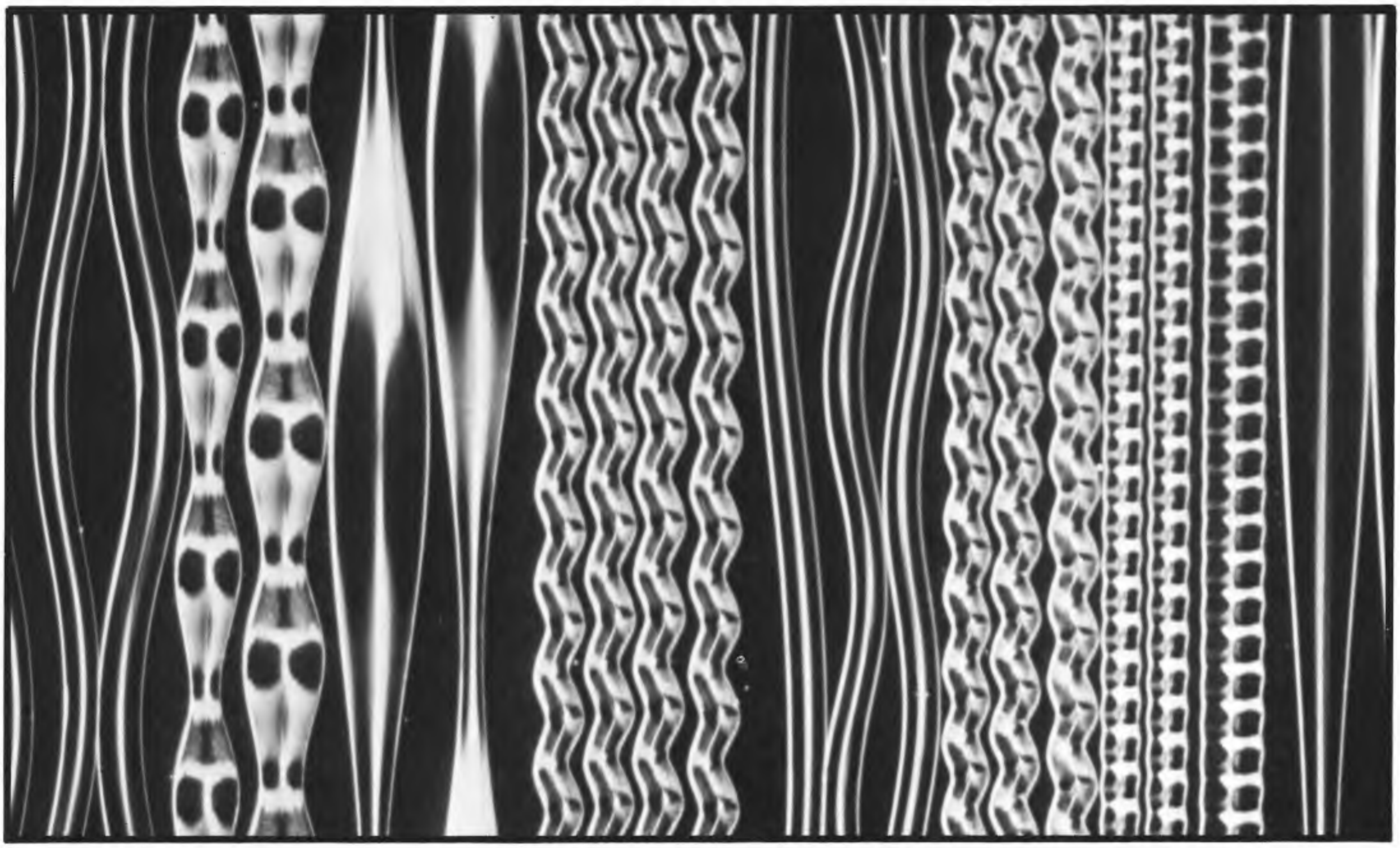
Let's solve this equation for a 1K tone cut at 7 centimeters per second. (Remember, that 1K at 7 CMS is zero level in the disc world.)

$$\text{Amplitude of Displacement} = \frac{7\text{CMS}}{6.28\ (1000)}$$

= .0011 CM = .439 Mils Peak Displacement

It is only necessary to double this amount to give us our peak to peak displacement. In this case - .878 Mils.

This formula is often used in conjunction with Buchman-Meyer light pattern observations.



Half Speed Mastering

Half speed mastering seems to be a relatively simple operation: Set the lathe turntable to run at half the desired speed (either 16-2/3 or 22-1/2) and then play the master tape at half its recorded speed. There's a bit more to it, as we shall see.

There was a time (the late 50's and early to mid-60's) when half speed cutting had a great many more practitioners than it does today. At that time, it was a tool of necessity. Stereo mastering was in its infancy, and it was often extremely difficult for engineers to cut sustained high frequency passages (such as cymbal crashes). To attempt to cut such sections or peaks often meant risking physical damage to the cutterhead or unsatisfactory groove geometries.

Since the speed of both the tape machine and the cutting lathe are halved, the frequences thus processed are also cut in half; therefore, 10KHZ becomes 5KHZ, 2KHZ becomes 1KHZ and so on. In real time cutting, the cutting system handles material above 10K continuously. At half speed, information over 10K is rare.

Maximum groove velocities are lowered by two also. The amount of power used to drive a cutterhead is directly proportional to the stylus velocity at a given level. This means that the cutting amplifiers will work at a much lower power level, an advantage in terms of coil temperature and the ability to bypass any sort of high frequency limiting device.

The physical setup for half speed mastering is only slightly different than that required for real time cutting. One noticeable difference is the need for half speed DBX and dolby units, caused by the fact that both devices are frequency selective.

One other notable factor is the increase of time needed to master discs at half speed. An album side that runs 20 minutes in real time will, of course, take 40 minutes to master. Additionally, several reference lacquers may have to be cut and then auditioned since music at half speed bears no relation to music at full speed, thus eliminating any kind of subjective monitoring situation.

The JVC CH-90 cutterhead, originally developed for half speed mastering.

The Buchman-Meyer Calibration Check

In the early days of disc cutting, cutting heads were not always linear in their frequency response. In 1930, Gerhard Buchman and Erwin Meyer were the first to document a satisfactory method of checking this response.

It had long been known that the light reflected from a cut disc had some relation to the cut information. The Buchman-Meyer technique used this fact in finding out how to check the response of a system.

First, a series of tones are cut on disc, making sure each one lasts at least ten turntable revolutions. When a light is mounted at a 45° angle from the turntable, the light that is reflected from each band will form a pattern, ideally forming a "christmas tree" pattern.

Remember that these various tones are etched into the disc by the cutterhead. The level of these tones is known as the "stylus velocity". Stylus velocity is the excursion of the cutting stylus when a sine-wave signal is applied.

"Groove velocity" is the speed of the medium relative to the stylus point. Mathematically, it is stated:

$V = 2\pi RN$

V = Groove Velocity

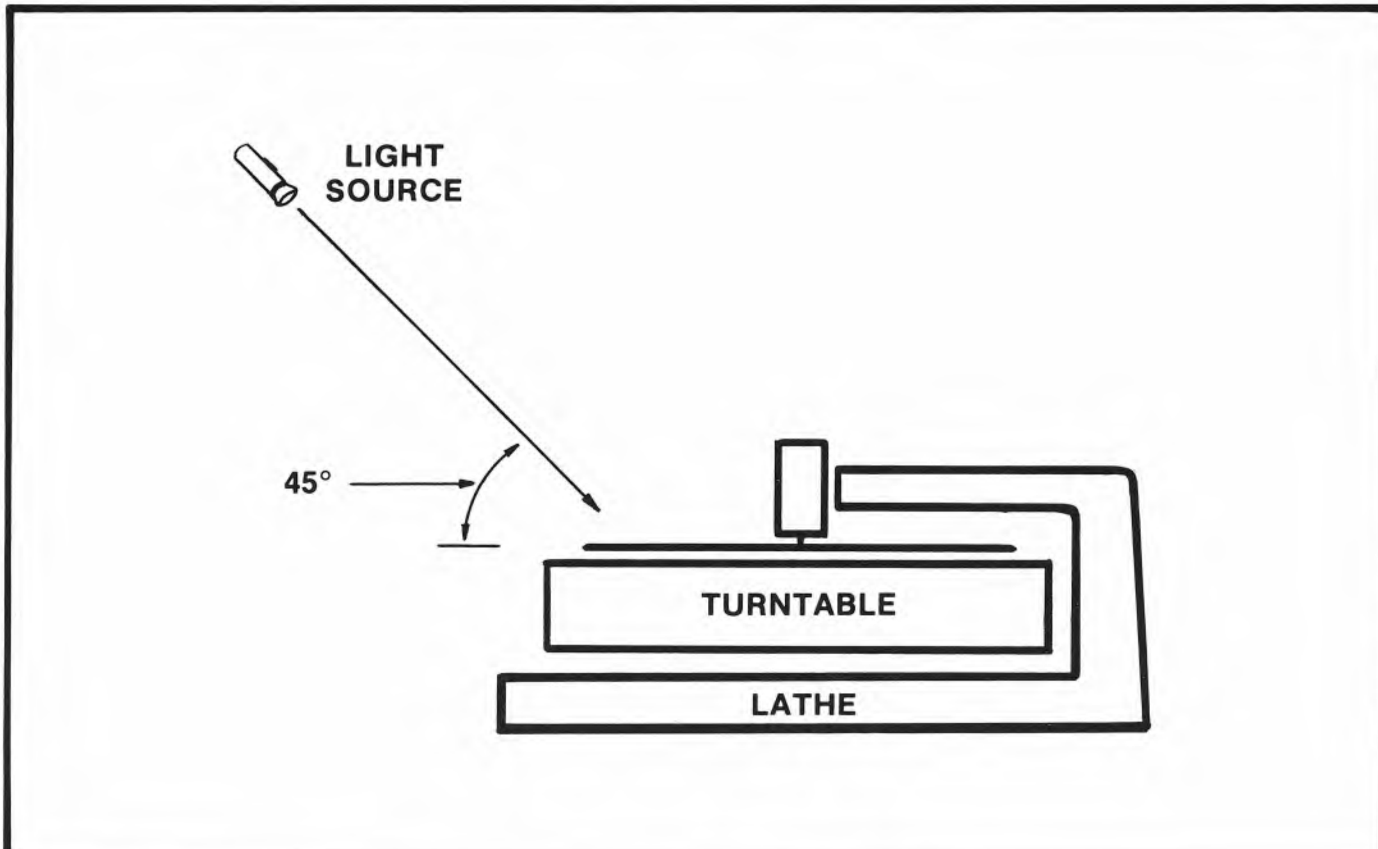
R = Radial Distance from the Center of the Disc to the Chosen Point

N = Turntable Rotational Speed

Of course, groove velocity is at its highest at the outermost diameter of the disc and at its lowest at the inner diameter.The wave length is decreased from outside to inside.

The Buchman-Meyer technique is of little use below 1,000 cycles since the lower frequencies are usually recorded at constant amplitude rather than constant velocity. In which case, the width of the light pattern decreases in proportion to the frequency decrease.

The Buchman-Meyer technique was the industry rule of thumb until the advent of dynamic feedback cutterhead. These heads proved to be extremely stable and response linear.



Correct physical procedure for observing light patterns.

Recorded Level on a Record

One of the most important judgments made by the cutting engineer is the amount of "level" or volume a given record will have.

Most cutters will state that the most common request given them by producers is for more volume and more bass. Sometimes more of one precludes more of the other.

After weighing factors like total running time, treble, bass, type of music, amount and intensity of vertical information, and the producer's and/or the artist's tastes, a final decision on the volume of the record will be made.

The accepted reference level is 7 CM/per second lateral at 1,000 cycles. Usually albums are cut 2 or 3 DB above this level. 45's are normally set at 4 or 5 DB above. These are only ballpark figures, of course. The volume of each record is determined by some or all of the factors mentioned in the previous paragraph.

Many recording engineers confuse zero level on tape with zero level on disc. They are the fruit of different methods of information storage and bear no relation to each other. Just because a tape is recorded at 6 DB above tape level zero doesn't automatically mean the corresponding record will come out at 6DB above record level zero. The cutting engineer will adjust the volume, either up or down, in his transfer procedure.

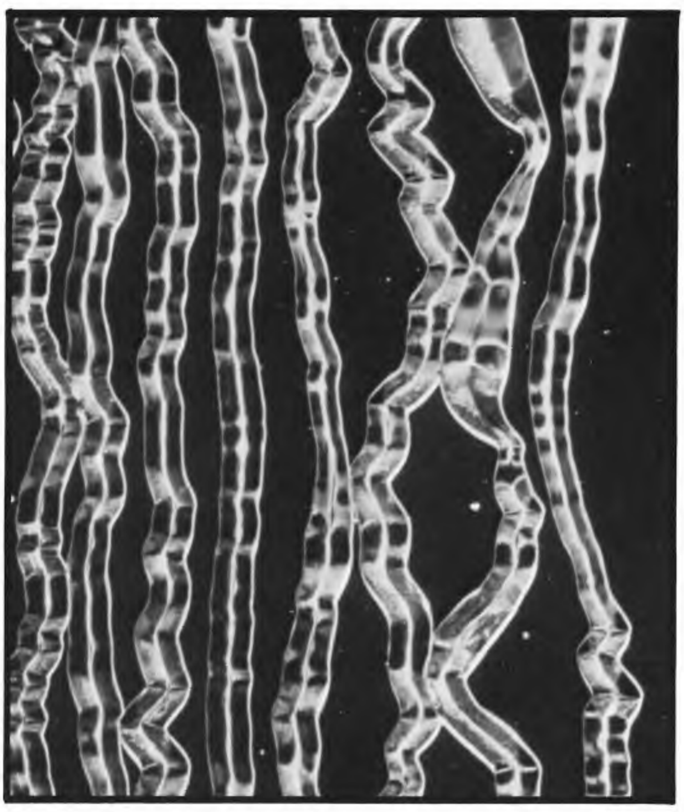
The most common problem caused by excessive level is mistracking of one sort or another. The record company wants its product to play on turntables, both good and bad, old and new.

In the other direction, excessively low levels allow for a rise in pressing noise in relation to the recorded material.

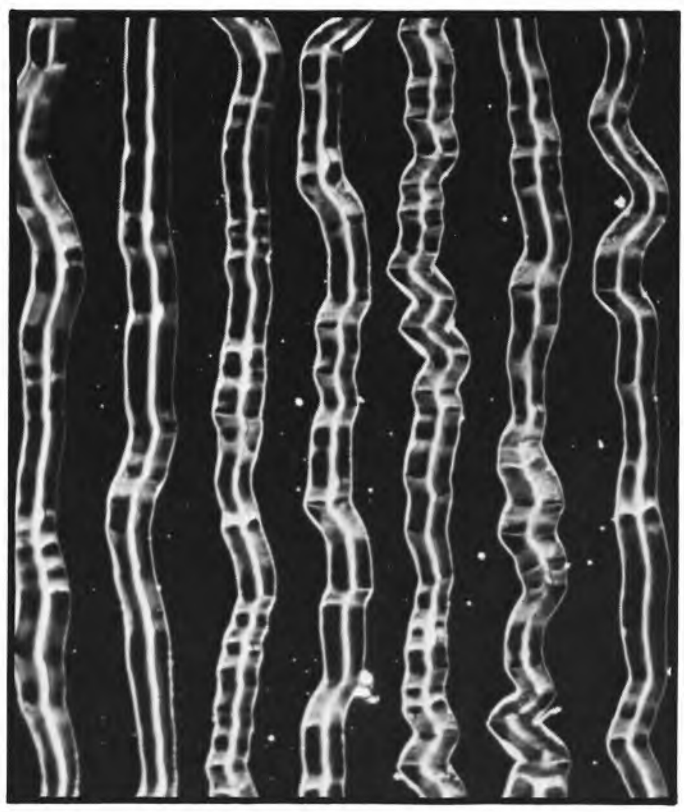
Excessive high end opens up a real Pandora's box of problems. Due mainly to the RIAA pre-emphasis curve, high volume and/or sustained treble information can damage a cutterhead or overload the cutting amplifier itself. This same treble information can result in groove modulations too rapid or too complex to be traced by even the finest playback cartridge. A typical example would be "sibilance" or excessive "S" sound in vocals.

Some recording artists (mainly female) who are inclined to exhibit this problem have their records "de-essed" electronically or cut at a lower level to compensate.

Sawtooth waves or muted trumpets cause much of the same problems.



Excessive cutting level can lead to overcutting.



Acceptable high level cut.

Diameter Losses

As the cutting stylus moves towards the center of the lacquer, the amount of acetate passing under it declines dramatically. The term for this is peripheral groove speed.

At a speed of 33-1/3 (1.8 seconds per revolution) the length of the groove passing under the stylus is in direct relation to the radius of the disc at that time.

The beginning groove on a standard LP side is just under 36 inches. We can compute our groove speed at 20 inches a second by remembering our turntable revolution speed of 1.8 seconds.

At the minimum closing diameter, our groove speed is a mere 8.3 inches per second. The recorded matter is put on the disc 2.409 times as dense, not an ideal situation. The result — diameter losses.

These losses manifest themselves in three distinct forms:

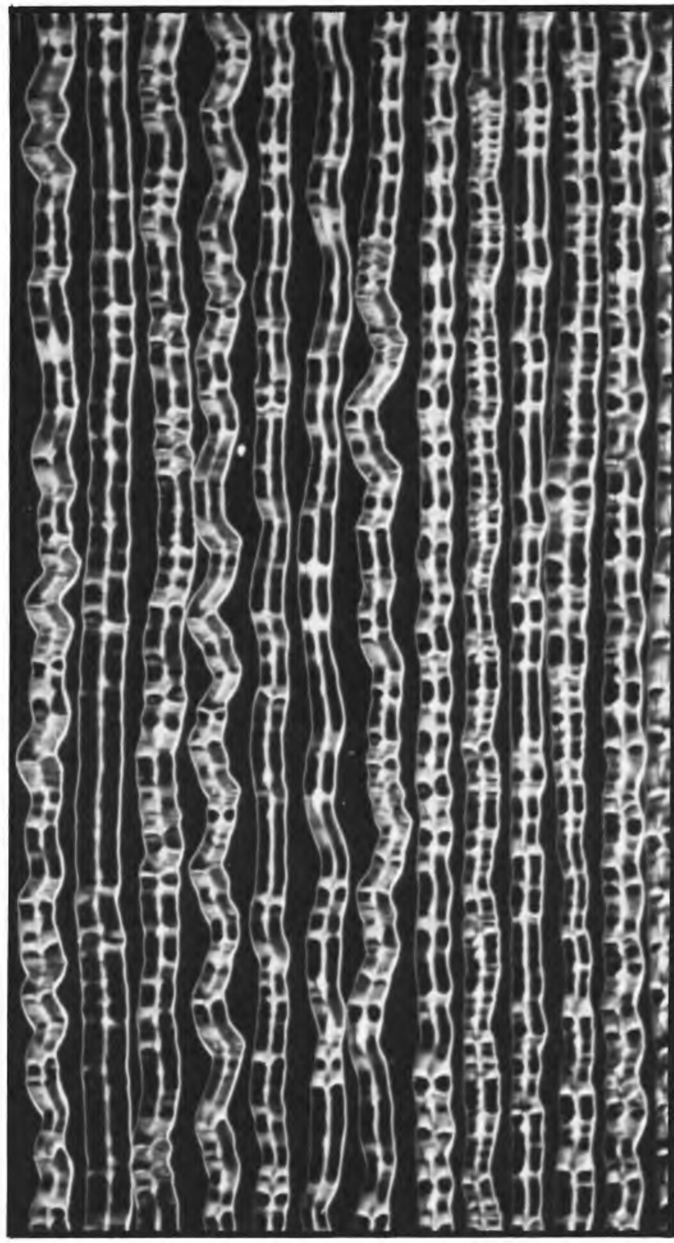
1. Cutting losses
2. Tracing losses
3. Deformation losses

Cutting losses come about due to the width of the burnishing facets of the cutting stylus. With the combination of high frequencies and severely reduced groove speed at the inner diameter, some self-erasure occurs. This loss cannot be measured except by light pattern observation.

Tracing losses are a function of the playback process — failure of the playback stylus to accurately "trace" each and every groove undulation. Styli will often take short cuts and miss minute sections.

Deformation losses account for more problems than the previous two types combined. Both lacquer and vinyl actually "give" under the stress of the playback mechanism. Worn playback styli, heavy tracking weight, and poor vinyl compound the problem.

The problem of diameter losses has been observed since the advent of the disc medium. From time to time some companies have employed a correction network which automatically added "corrective" equalization as the disc radius decreased. The use of these devices was gradually abandoned, due to lack of any measurable success.



Slower disc speed can result in very complex grooves towards the inner diameter.

Practical Considerations

Mastering is a unique function in the recording and manufacturing process.

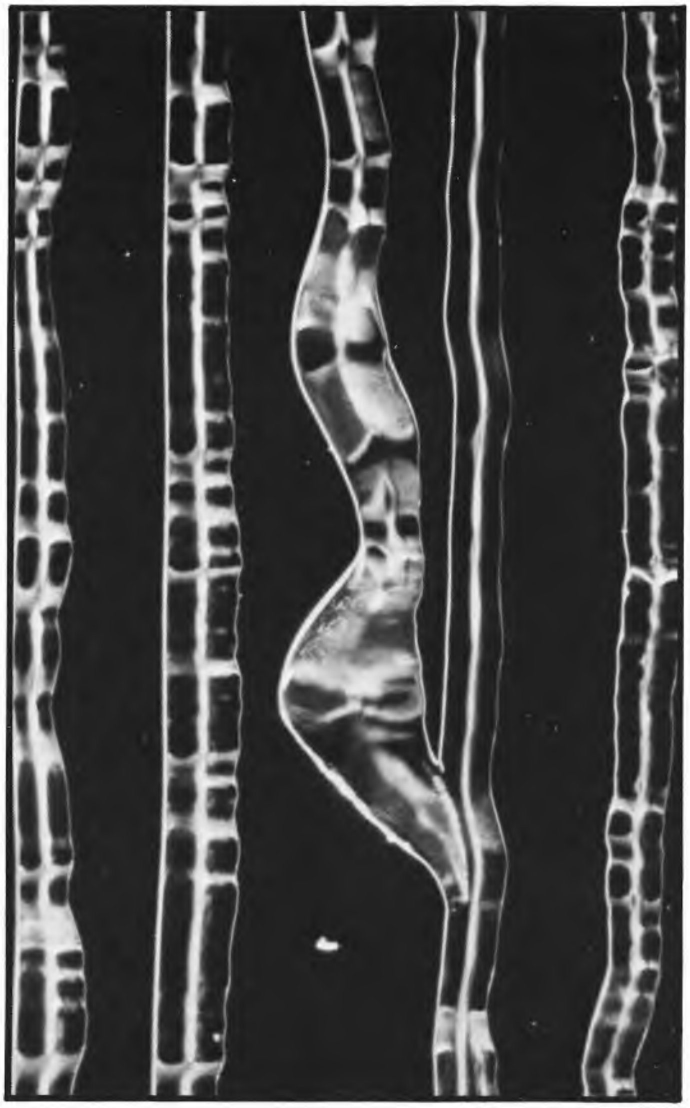
While it is actually the first manufacturing step, it is also the last creative process, bridging the gap between the two.

It happens more than seldom where the sonic qualities of the disc are less than the producer, artist or mixing engineer had hoped for.

Several things can hinder the mastering process from achieving its full potential. A little care in tape preparation and a little extra time in documenting the tape box can help immensely.

Let's discuss a few of these problem areas:

1. **Tones.** Having no set of master tones with your tape is pure treason. Standard alignment tone tapes will be used in their stead. Their level and azimuth may or may not bear any relation to yours. Tones should be recorded on both channels at once. They should also last about 30 seconds each. The first tone should set the operating level and channel balance (usually IK). The second is normally for azimuth (5 to 10K). The third for high end EG (12 to 15K). The last one is for low and EQ adjustment (50-100 HZ).
2. **Noise Reduction.** Mark the box with the brand name. If you use dolby on your mix, you must include a dolby tone at the tail of your alignment tones. For DBX, include an encoded IK tone in its place.
3. **Banding Times.** While leader tape is nice to have between selections, it is not necessary, and, at times, undesirable. Exact times of each selection are a necessity and a cumulative time log is ideal. Such a log might read: band at 3:20, 6:41, 8:11, 12:38, 15:59. It's also nice to give the cutting engineer a warning about abrupt endings or buttspliced seques.
4. **Sequence of Tunes.** The running order of selections can affect the overall sonic quality. An upbeat high energy cut with pronounced top end can create a problem on the inner diameter. (See Chapter on Diameter Losses). A nice ballad or less intense cut is often a better choice.
5. **Undocumented Flaws.** Any obvious flaws on the tape (distortion, odd channel balance, etc.) should be noted on the tape box.
6. **Format Uniformity.** It's also nice to get a tape in which:
   a. All the cuts are the same speed. It's almost impossible to change from 30 to 15 IPS between selections.
   b. Noise reduction is uniform — changing from DBX to dolby is similarly difficult.
   c. The songs are in the correct order on the correct reel — resequencing takes time.
   d. The master numbers to be scribed are furnished along with shipping instructions for the master discs.



A sudden flash peak can be a real disaster. Noting such peaks on the tape legend can be a real help to the engineer.

How Records Are Pressed

Upon arrival at its final destination, the manufacturing facility or "pressing plant," our master lacquer finds itself subject to the somewhat cruel demands of mass production.

The first step is careful unpacking and a thorough visual inspection of each disc. Occasionally oils in the acetate coating will "bleed" or shipment damage will occur, usually from exposure to high temperature. At this point, the disc will be rejected and the mastering studio notified to recut the problem sides.

Secondly, the acetate is thoroughly cleansed with a mild detergent and distilled water to remove any dirt or dust. Next, it is immersed in a solution of stannous chloride (tin). Since we are going to be making several metal parts or "molds" from which plastic records will be pressed, we will be dealing entirely with metal from this point on. This layer of tin will help to attract a layer of silver in the next process.

The disc with its ultra-thin coating of tin is now locked in position atop a circulating drum and sprayed once more. This time a silver nitrate solution is used to coat the disc. This silver coating will help in the next process to allow nickel to accumulate on the disc.

The silvered lacquer is attached to a rod and immersed in a nickel sulfamate solution. A DC current of low force is run through the solution. Nickel comes out of solution to form on the disc. The thickness of this coating is determined by the amount of time the lacquer is left in the solution. If this process is too rapid, stresses will occur in the nickel crystals closest to the surface, thus deforming the soft lacquer and causing "groove echo".

The disc is then taken out of solution and the lacquer is separated from its metal coating. Great care must be taken so that no silver is left behind on the lacquer. The separated nickel build-up is called the "metal master". The metal master is a negative copy of the original lacquer. The grooves on the master disc become raised ridges on the metal master. The surface of the metal master is now

Silvering the master lacquer.

Once coated with nickel at the proper thickness, the acetate is removed from solution.

chemically treated so that a second nickel plating can be built up on its surface and easily separated.

The metal master is now reimmersed in the nickel bath until the second coating is of the desired thickness. The two plates are now parted and our metal master has now given birth to a "metal mother". The metal mother is a positive copy of our original master lacquer. The original grooves of the master are now grooves again on the mother.

Since the mother has grooves, it can be played on a turntable. The swishes, grittiness, pops and ticks often heard on finished pressings are the result of some flaw in the spraying, separation or the materials used in the process up to this point.

A less than satisfactory metal mother can often be repaired. If the separation of the master and mother was improper, oftentimes small areas of the master will be imbedded in the groove area of the metal mother. Through a process known as "de-ticking," an experienced person can remove this debris with a sharp plastic instrument and a fine abrasive powder. This job takes steady nerves and a strong microscope.

Separating the acetate and the metal master.

Separating the metal master and the mother.

Another process used at this stage is called "dehorning". Horns are small ridges at the top edge of the groove wall that happen in the original cutting, usually because of excessive stylus heat. These horns greatly complicate the vinyl molding process. At best, dehorning is difficult, and many companies do not perform it on every mother. There is an extremely easy way to tell if a record has been dehorned: When the playing area is rubbed with a soft cloth, no scuff marks will show, whereas just the opposite is true if the mother used for that record has any degree of horns.

The final stamper is separated from the metal mother.

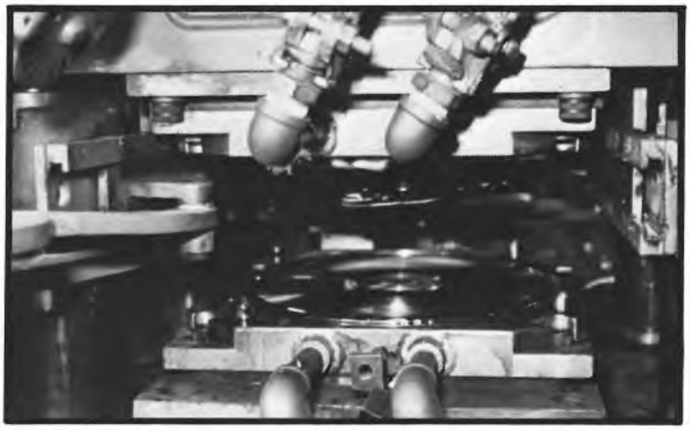
After dehorning, the mother is prepared for the final metal step — the making of the actual stampers themselves. The mother is again immersed in the nickel bath for the forming of the stamper. The stamper is separated from the mother and a precise center hole is carefully made to aid its mounting in the record press. An off-center hole will result in off-center discs, which will "wow" in pitch each revolution.

Polishing a metal mother helps get rid of "horns".

With the hole process complete, the back of the stamper is sanded both by hand and by machine to assure both a tight fit in the press and a smooth pressing surface. If this operation is done hurriedly or carelessly, any irregularity left will go right through to the vinyl and cause a graininess effect

A stamper ready to go to press. Note carefully punched center hole and fluted edge.

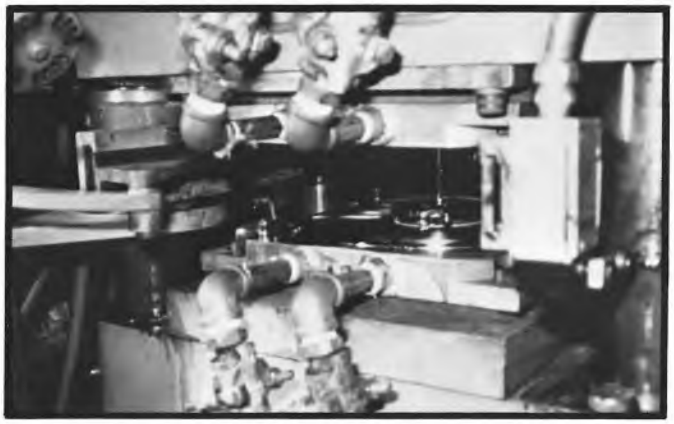
commonly called "orange peel". Orange peel increases rumble greatly and is easily visible to the naked eye. Stampers, although strong, are comparatively thin and any sanding flaw or dirt trapped



A stamper mounted in a record press.

behind them will show up visually.

We are now ready to begin the pressing process itself. The stampers are bolted into the cavity of the record press. Centering the stamper in the press is critical, since a stamper thusly mounted will cause an off-center record.



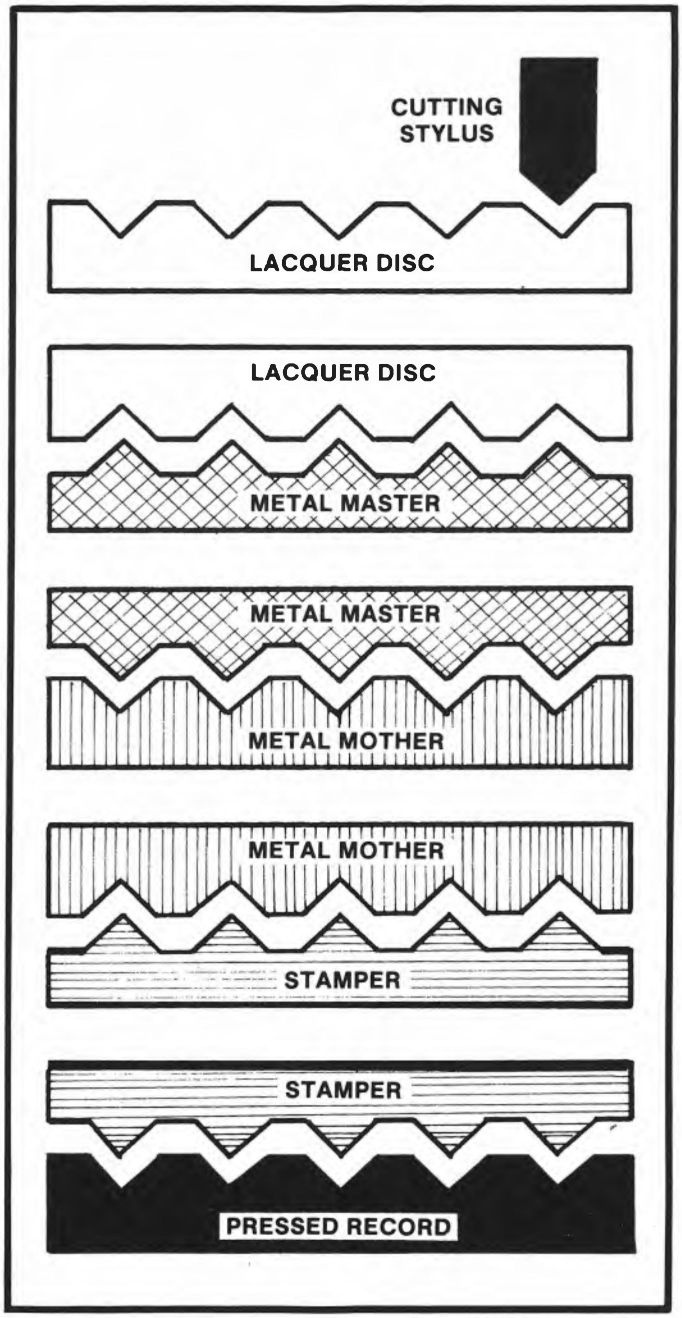
The warm vinyl biscuit in place in the center of the stamper.

The vinyl used in records reaches the pressing plant in a granulated form. Vinyl in its natural state is not black, but a honey-amber. Coloring matter, lubricants and stabilizers are added for record pressing used. Sometimes a plant will salvage plastic from defective records or use the "flash" (excess vinyl trimmed from the edge of finished records). Recycling vinyl is somewhat risky since contamination is possible from foreign material such as paper labels. The vinyl is heated until it has the form of modeling clay in a device known as an "extruder".

The hot biscuit is placed in the cavity of the record press. A label for each side of the record has been put on each side of the vinyl biscuit. The press closes on the biscuit much like a waffle iron. Here the vinyl is heated to about 300°. Ideally, the vinyl should fill out every groove indentation and turn in the groove precisely; whether it will or not is largely a factor of pressure (a typical press produces pressure approaching a ton per square inch), temperature, and the texture of the vinyl.

After the passage of a preset time, cool water is pumped into the die behind the stamper. This process firms up the vinyl record. The press will open after another preset time interval.

A lot of things can happen to our record while it's in the press (most of them bad). Too hot a press will cause a warped disc, too cold will give us a noisy one. If the vinyl disc does not separate from the stamper, we achieve a condition called "pull out". Pull out on a finished record sounds like a metal file rubbed against a china plate and is often visible to the naked eye. Complicated groove geometry aggravates this condition.



The various stages in the pressing process. Noise and other flaws can be introduced at any stage.

Excess vinyl is trimmed from our finished record by one of two ways. A "hot knife trimmer," razor sharp, travels the disc circumference and trims the "flash," as the surplus vinyl is called. A "dinker" can also be used to punch out the record in one fell swoop.

The record is stacked on a spindle to cool to room temperature. After a quality control inspection, the finished pressing is sleeved and inserted into the correct jacket (hopefully).

The final process is the application of the cellophane "shrink wrap". This is done by passing the jacketed disc through a heat tunnel. The temperature of this process must be carefully monitored, as too much heat will "bow" the disc and cause dish warpage.

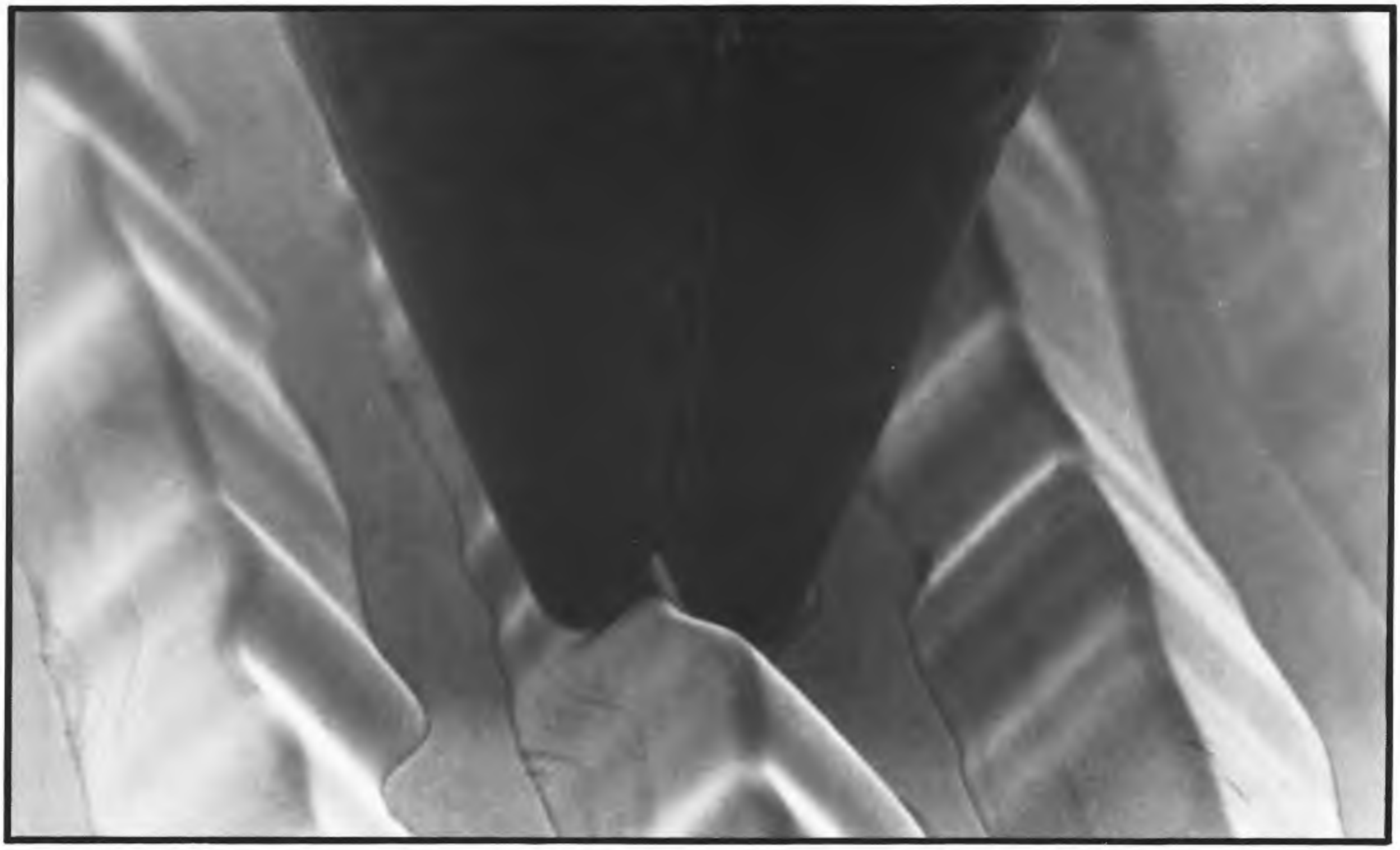
A modern, automated record press.

A pressed record before the flash has been trimmed.

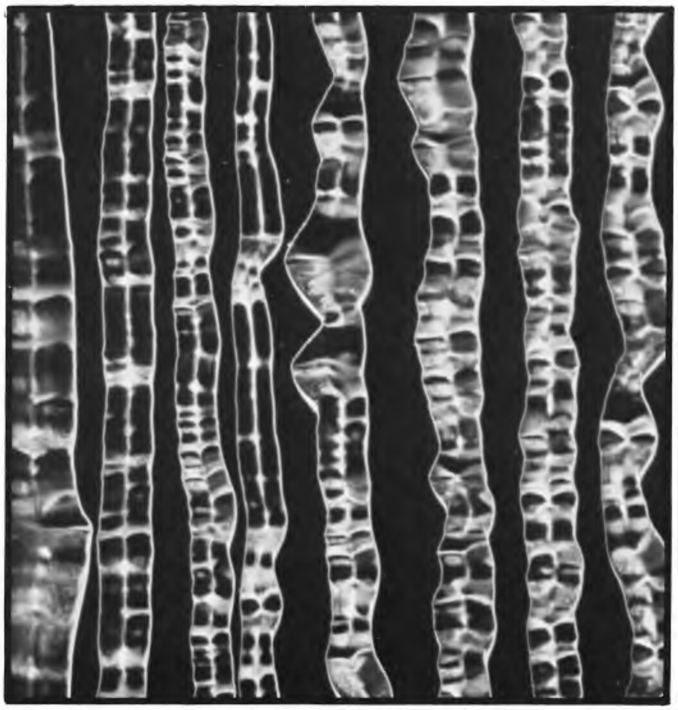
Past the point of danger? Not on your life! Excessive heat or moisture in shipment or warehousing, improper stacking or storage, and rough handling can all contribute to the all too frequent defective record.

Quality control methods vary from plant to plant. Careful visual inspection is a must.

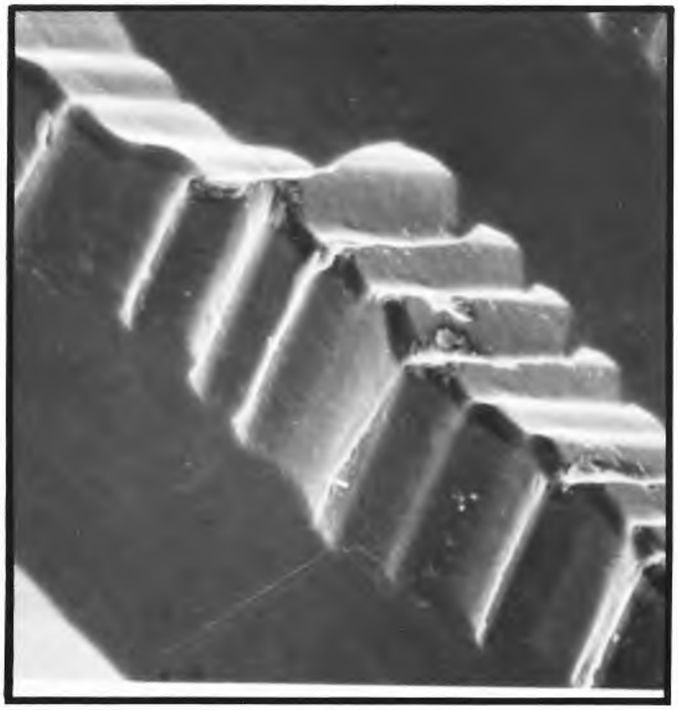
Packing and shipping are also important.



This special stylus plays only stampers and metal mothers. As can be seen in this remarkable photo, it straddles the negative groove.



Complex groove geometries can often cause pressing problems. The vinyl must fill every nook and cranny, much like hot butter on an English muffin.

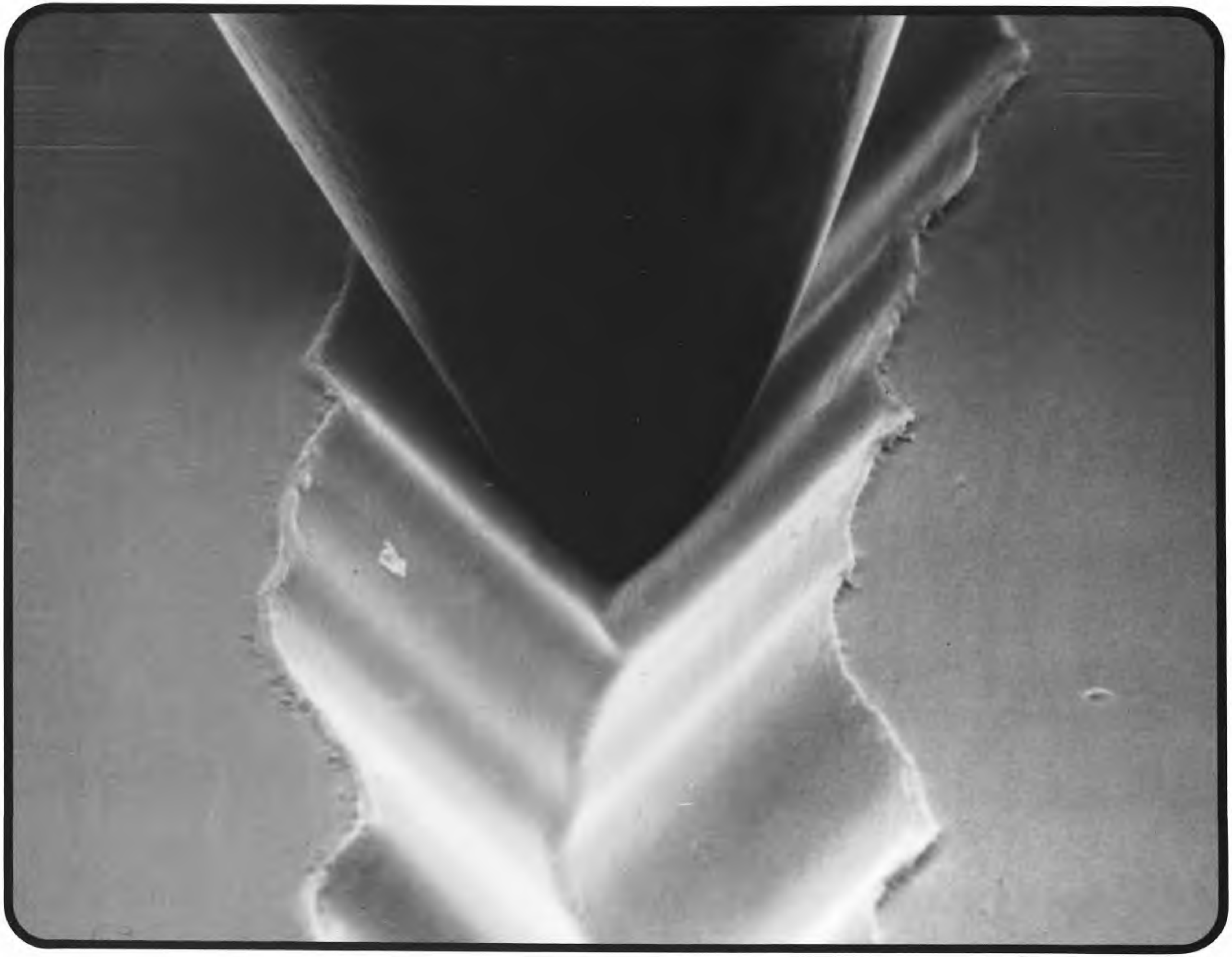


This photo shows the raised grooves of a metal master. The debris to be removed by de-ticking are clearly visible. (Photo courtesy of Stanton Magnetics)


Westrex
Litton
StereoDisk
3D IIA RECORDER
MADE IN U S A

Common Record Defects

DEFECT	CAUSES
WOW	Off-center record, caused by the center hole in the stamper being off, or by off-center mounting of the stamper in the press.
THUMPS	Dimples caused by gas in compound; also dirt under the stamper or poor die repair; dented stamper.
TICKS + POPS	Press not heated to operating temperature, poor silvering of lacquer, impurities in vinyl.
SWISHES	Excessive "horns"; bad vinyl; bad separation.
GRITTINESS	Nonfill; worn stamper; faulty separation.
RUMBLE	Improper sanding of stamper back; badly worn die.
PRE-ECHO	Improper groove expansion; variable pitch undershoot; too fast initial plating of master.
INNER GROOVE DISTORTION	Ending diameter too small; recording level too loud; wrong equalization.
ROAR IN LEAD IN GROOVE	Bad "coining" or lead in groove has excessive depth.
RASPY, SCRATCHING SOUND	Crushed grooves on stamper. Happens when the press closes with no vinyl.
"DISH" WARPAGE	The record will be shaped anywhere from a bowl to a hubcap. Due to small difference between the press die and stamper thickness. Also, improper stacking of warm records.
"PINCH" WARPAGE	The record will be warped in a 15 to 40° arc. Caused by improper removal of record from press; improper trimming of flash; record trimmed when too hot.
"SADDLE" WARPAGE	Record bowed on one diameter; improper storage; warped record jackets; shrink wrap too hot when applied.
REVERSED LABELS **WRINKLED INNER SLEEVE** **WRONG RECORD IN JACKET** **TORN LABELS** **FINGERPRINTS ON RECORD**	All caused by human incompetence.



Playback stylus resting in a groove (1,000 magnification). Severe "horns" are visible at the top of each groove wall, typical of an inferior pressing. (Photo courtesy Stanton Magnetics)

Commonly Accepted Dimensions and Standards for Recorded Discs

UNMODULATED GROOVE WIDTH
2 MIL MINIMUM, 4 MIL MAXIMUM

OUTSIDE STARTING DIAMETER

7″ DISCS	6.78″	+.06-.00
10″ DISCS	9.72″	+.06-.00
12″ DISCS	11.72″	+.06-.00

START MODULATED PITCH

7″ DISCS	6.63″	-.03 +.00
10″ DISCS	9.50″	-.03 +.00
12″ DISCS	11.50″	-.03 +.00

NOTE: Pitch should be under 200 LPI 2 to 3 seconds after lead in spiral completion

MINIMUM INSIDE DIAMETER

7″ DISCS	4.25″
10″ DISCS	4.75″
12″ DISCS	4.75″

LOCKOUT GROOVE DIAMETER

7″ DISCS	3.88″	+.00 -.08
10″ DISCS	4.19″	+.00 -.03
12″ DISCS	4.19″	+.00 -.03

LEAD OUT
Must contain one complete revolution at lead out pitch. Pitch should be under 200 LPI 2 to 3 seconds before lead out.

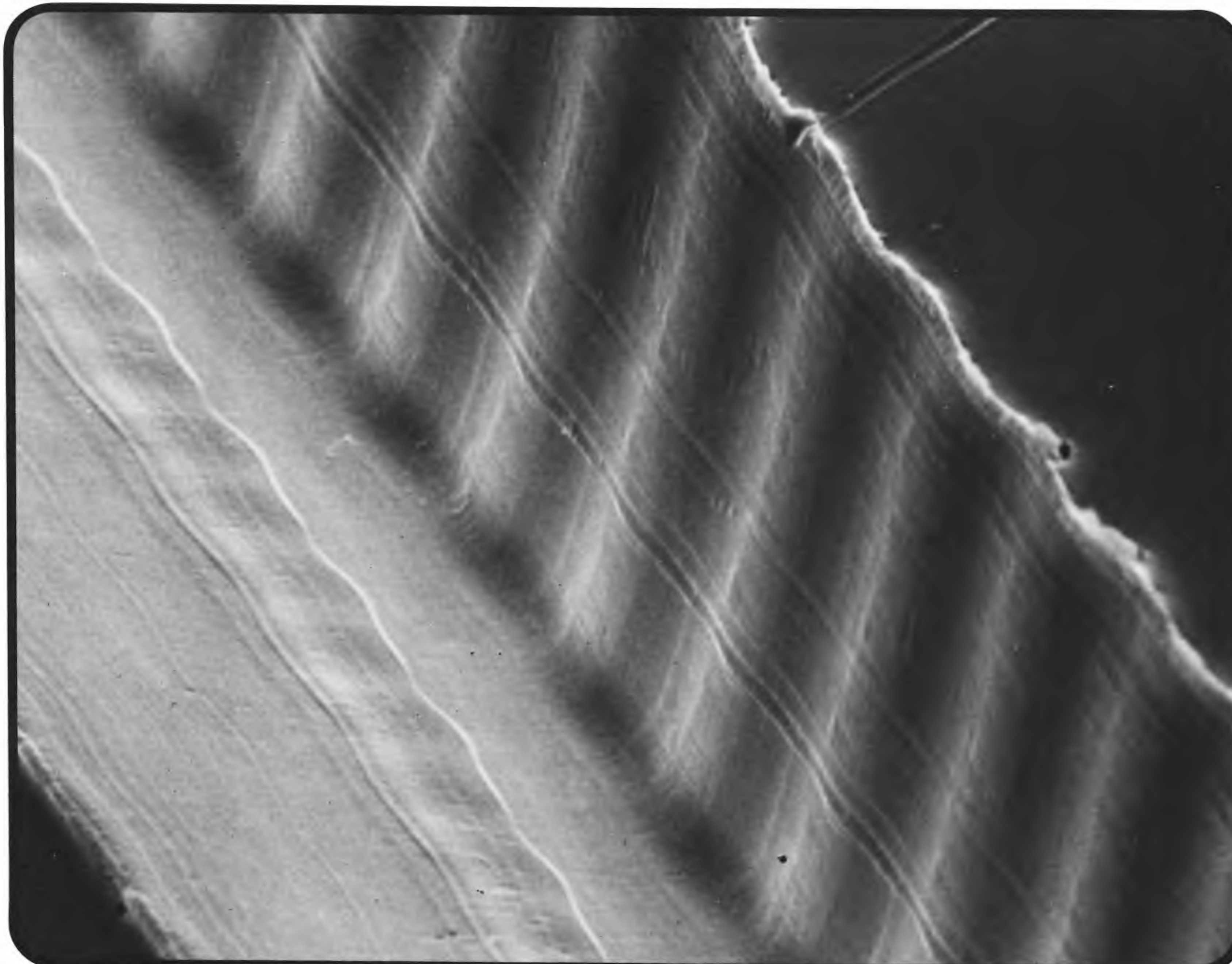
SPIRALS
At least 16 LPI, not more than 32 LPI. Pitch should be under 200 LPI 2 to 3 seconds pre and post spiral.

MODULATED GROOVES
Maximum depth, 5 Mil. minimum, 1 Mil. Each lacquer must contain one continuous groove with adjacent land. The groove must not cross over itself or cut into itself in a way which compromises groove wall integrity.

A spherical playback stylus resting in a record groove in playing position (10,000 magnification). (Photo courtesy Stanton Magnetics)

The RIAA Recording Equalization Curve

FREQUENCY IN HZ:	DB
20	- 19.3
30	- 18.6
40	- 17.8
50	- 17.0
60	- 16.1
70	- 15.3
80	- 14.5
100	- 13.1
110	- 12.4
125	- 11.6
150	- 10.2
200	- 8.3
250	- 6.7
300	- 5.5
400	- 3.8
500	- 2.6
600	- 1.9
700	- 1.2
800	- .7
1,000	0
1,500	+ 1.4
2,000	+ 2.6
3,000	+ 4.7
4,000	+ 6.6
5,000	+ 8.2
6,000	+ 9.6
7,000	+10.7
8,000	+11.9
9,000	+12.9
10,000	+13.7
11,000	+14.5
12,000	+15.3
13,000	+15.9
14,000	+16.6
15,000	+17.2
16,000	+17.7
18,000	+18.7
20,000	+19.6



A test record after 100 plays. Note 20KHZ modulation on right groove wall, none on left (10,000 magnification). Groove wear is clearly evident. (Photo courtesy of Stanton Magnetic)

Glossary

CHIP .... The thread of acetate which is cut out of the groove. It is removed by a vacuum system thru a tube located at the rear of the cutterhead.

COINING .... The bending or tapering of the edge of the stamper so that it achieves a snug fit on the die. Too deep a lead in groove will cause early stamper fatigue and breaking of the edge.

COMPOUND .... The vinyl mixture from which records are pressed.

DIE .... The metal base to which the stamper is bolted in the record press.

DINKER .... A device which trims the excess vinyl from a freshly pressed record.

FLASH .... Excess vinyl trimmed off of a newly pressed record. It is remelted and re-used.

LPI .... An abbreviation meaning lines per inch. Sometimes expressed as GPI or grooves per inch.

LAND .... The areas of space between the grooves of a disc.

MASTER .... The nickel master is made by electroforming it from the original acetate. It is used for making new mothers. Additional metal masters can be made only from additional master lacquers.

MASTER NUMBER .... The identifying digits scribed into the lead out area of a master disc.

MIL .... The term used for one thousandth of an inch. Both groove depth and width are expressed in mils.

MOTHER .... Made from nickel, it is an exact duplicate of the original acetate. Additional mothers can be made from the metal master. Mothers are used to make more stampers.

NON-FILL .... See UN-FILL

ONE STEP PROCESSING .... A process where a set of stampers are made directly from a set of master lacquers. Used only for short runs due to limited stamper life. Additional stampers must be made from additional acetate masters.

OVERCUT .... A condition where adjacent grooves intercut with each other.

PEAK METER .... A level monitoring device which senses and shows instantaneous levels rather than averaging the peaks. Sometimes known as PPM, standing for Peak Program Meter.

PINCH EFFECT .... The tendency of a playback stylus to ride over groove undulations and curves rather than around them.

PING PONG STEREO .... A term used to describe a stereo recording having very little or no center channel information.

PITCH .... The rate at which the cutterhead and stylus travel across the disc.

PRE-ECHO .... A condition where the sound of the next groove can be heard in the groove adjacently cut.

RF .... Abbreviation for radio frequency. Refers to that part of the frequency spectrum between audible sound and infrared light, about 10 KHZ to 10,000,000 MHZ.

REFERENCE LACQUER .... A direct cut acetate disc used for audition purposes. Similar in function to a proof photograph. Changes in level, EQ, etc., can be changed before final acetate masters are cut.

SCRIBING .... The numbering cut into the master lacquer. Located in the lead out areas of a record. It is used to match up the labels with the correct stampers.

SEPARATION .... The degree of isolation between two or more signals.

SHIBATA STYLUS .... A playback stylus originally made to play CD-4 quadrafonic records. It has small radius shoulders to more effectively trace the smallest wave lengths in the groove wall. It is more pyramidal in shape, with a larger curvature of its surfaces resting against the walls parallel to the modulation. Since the area of the stylus touching the groove is increased by four, many claim it wears a record less, because the weight of the stylus and arm are distributed over a large surface area.

SILVERING .... The initial coating applied to a master disc.

SPIRAL .... The visual spacing between selections on a record. Done by decreasing the speed (pitch) of the lathe.

STAMPER .... An electroformed production plate, solid nickel for hardness and durability. Used to press the vinyl records. Additional stampers can be made from the mother.

TEST PRESSING .... An actual pressing made from finished stampers for acceptance and approval.

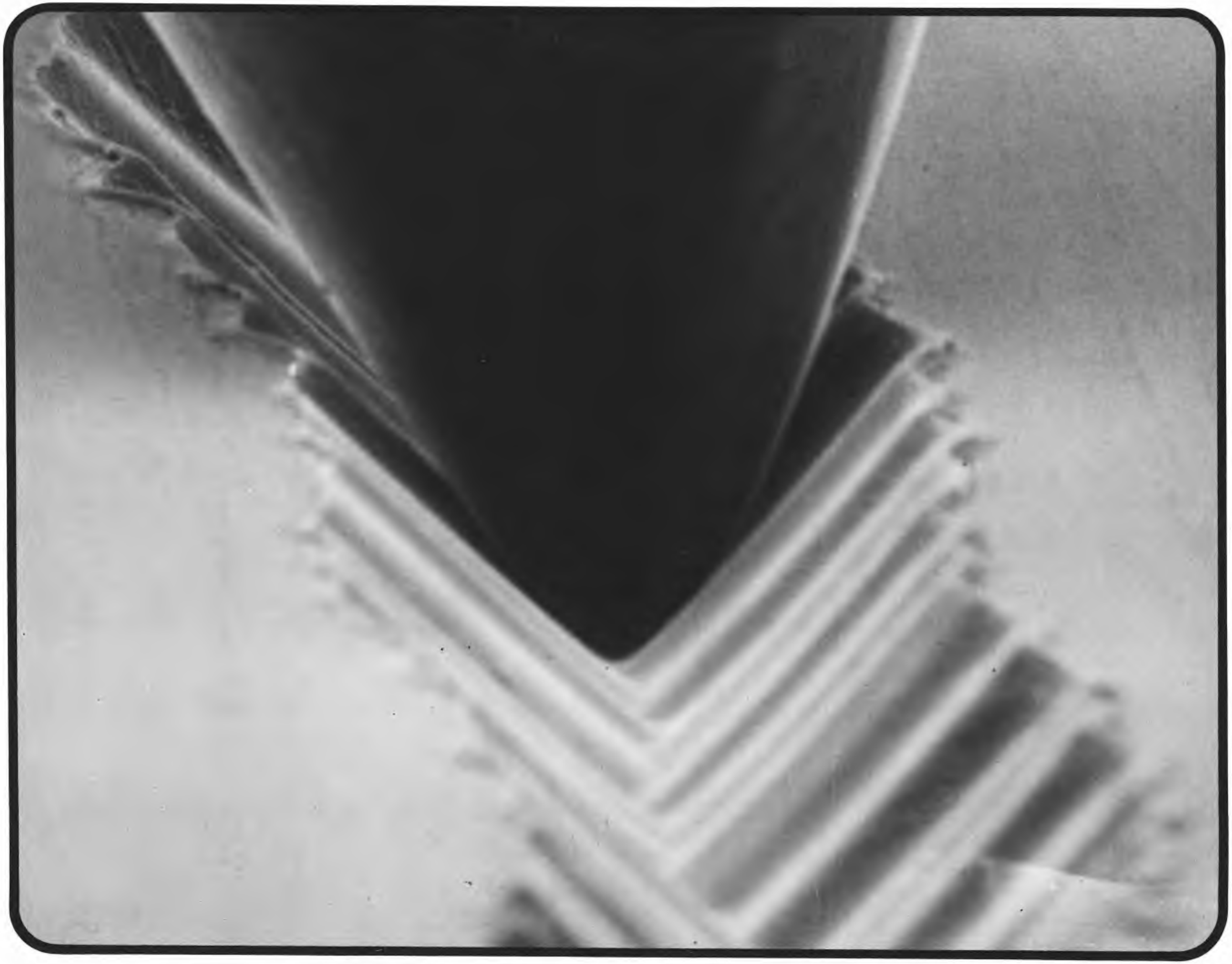
UN-FILL .... A condition caused when vinyl does not "fill out" every groove nook and undulation. Normally in the left channel.

VU METER .... A meter used for monitoring levels. It reads zero level on its range when the voltage equivalent to one milliwatt in 600 OHMS (.775 volts) is applied. Normally, an attenuator is put ahead of the meter so that its zero level reading is +4 DBM (1.23 volts).

WOW .... A slow periodic change in the pitch or frequency during recording or playback. In tape, normally caused by transport maladjustment. In disc, caused by an off-center record, most noticeable on piano.

WRAP .... That part of a tape's travel where it is in intimate physical contact with the head. It is sometimes measured as the angle of arrival and departure of the tape with respect to the head.

The raised grooves on a nickel stamper. (Photo courtesy Stanton Magnetics)



This photo shows just how hard a task the playback stylus has. Failure to completely trace out each and every groove undulation will result in distortion (1,000 magnification). (Photo courtesy of Stanton Magnetics)

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