A Real-Time Digital Processor for Disk Mastering Lathe Control*

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The availability of highly reliable LSI circuitry has made possible a major breakthrough in disk recording lathe control technology. A new system for optimizing the groove-to-land ratio is described which utilizes real-time two-dimensional relationships derived from the audio waveform. This system, based on 12 years' experience with analog designs, achieves a significant advance in the time/level/skill relationships of the phonograph disk when compared to all previous cutting equipment.

0. INTRODUCTION

The idea of changing the distance between grooves as a function of the recorded signal is certainly not a new one. Columbia Gramophone Company of London obtained a patent for it in 1929 [1]. Eduard Rhein of Hamburg obtained a patent in 1942 [2], which made the control signal not only dependent on the modulation to be cut, but also on the modulation of the prior groove. Both patents exceeded the technical possibilities of their time. Add to that the time lost during World War II, and we are into the fifties before we again find patents on this subject [3]–[5]. Among these is one from Neumann [6] which describes a system that at the time was actually manufactured in quantity. The ensuing improvements within the framework of optimizing the groove-spacing control (variable pitch) were really based only on improvements in the available electrical components. In 1966 Neumann introduced a purely analog computer using discrete transistor technology [7]. The basic knowledge, using the most modern components and assembling these into a groove computer according to the latest knowledge in the field, was gathered in a paper by Braschoss and Kern delivered at the 1977 AES Convention in Paris [8]. We will show the realization of these ideas today—but let us first go back to the description of the problem.

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1. THE PROBLEM

What is required is to optimally utilize the space available on a phonograph record. This means, in effect, to maintain the slowest lathe carriage travel at any given moment without thereby causing a collision between the grooves. Today's digital technology offers two completely different solutions to this problem.

2. POSSIBLE SOLUTIONS

One solution involves storing all the control signals needed for an entire record side in the memory of a computer, processing this information in a suitable manner, and retrieving from the computer a control signal that will operate the lead screw of the lathe throughout the cutting process.

The other solution is the real-time analysis; namely, storing certain portions of the signal during the tape-to-disk transfer process for short periods of time, correlating these with other signals which are just being cut, and obtaining from these the lead screw controlling signal.

Both possibilities have advantages and disadvantages. The first solution would have the advantage of providing a readout of the exact space requirements, but it would need an additional processing step; the entering of the information. The real-time method, on the other hand, requires a sophisticated computer to permit obtaining optimum lead screw drive during the very short time that the signals are available.

We opted for the second method, for we wanted to avoid the additional, time-consuming, and therefore uneconomical processing step. It is still possible to prerun the program with the cutter up without spoiling a lacquer in cases where playing-time complications are anticipated. As indicated, the real-time analysis requires considerable computer sophistication, and one must utilize the signals carefully if optimum space utilization is to result. The problem is so complex that it cannot be solved using only a single-step approach.

3. THE VMS 80 SOLUTION

In Fig. 1(a) two neighboring grooves are shown in a schematic fashion. Curves 1 and 2 show that the traditional pitch control, which uses the peak envelope of the signal curve, has worked correctly. Were it but possible to use the individual maximum values and their phase relationships to one another rather than the traditional peak envelope, an even closer groove-to-groove spacing would be possible. This is shown in Fig. 1(b). Today's IC components make this sort of control economically feasible. It is necessary to store the information of the left (inner groove) flank for exactly one full turntable revolution and compare it with that of the right (outer groove) flank (Fig. 2). The sampled memory, which in our unit is a digital delay, must be exactly synchronized with the angular velocity of the turntable. That is why one controls both memory and turntable speed, as well as all other control functions of the machine, from a central crystal time base. For suitable phase relationships of the signals such an arrangement permits the "snuggling" of two adjacent grooves up against each other, as the microscope picture of Fig. 3 shows. Natural sound phenomena will only seldom provide such advantageous relationships as those obtained here through the use of test signals. That is why we have searched for further possibilities of groove-space economy. The method which we developed provides for the optimum utilization of the space created for a particular modulation signal by the preceding amplitudes. This space, which the following signals can utilize, has been called the "rest space."

To better understand this rest-space utilization, it is useful to replace the continuous modulation signals with single impulses of varying magnitudes. Fig. 4 once again shows two adjacent grooves. The time between t_1 and t_1', between t_2 and t_2', and so on, is always half a turntable readily seen. S_3 is substituted for S_1 as the pitch-

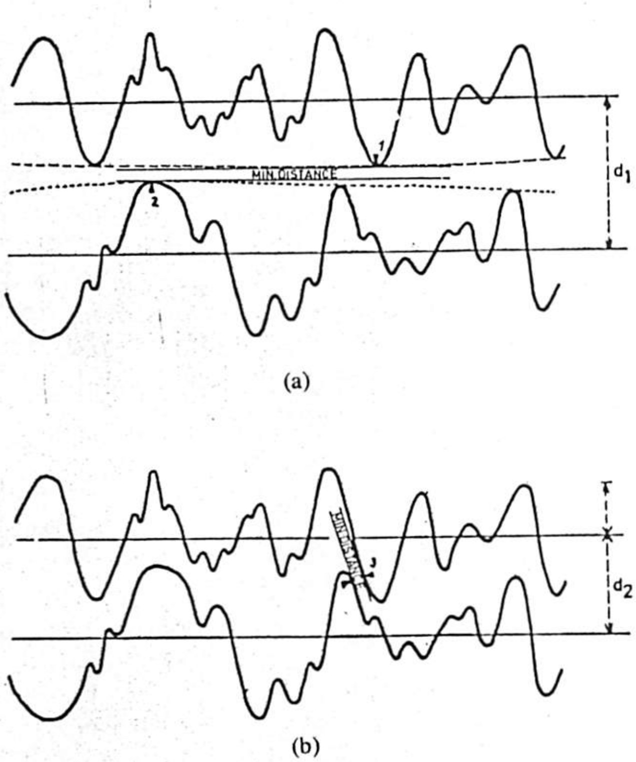

Fig. 1. Schematic presentation of two neighboring grooves with pitch control. (a) Peak envelope method. (b) Phase recognition method.

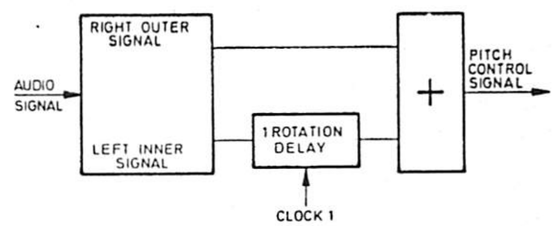

Fig. 2. Schematic block diagram of a phase recognition system according to Fig. 1. The inner flank signal is stored for exactly one full revolution and is compared to the signal portion of the outer flank of the groove then being cut.

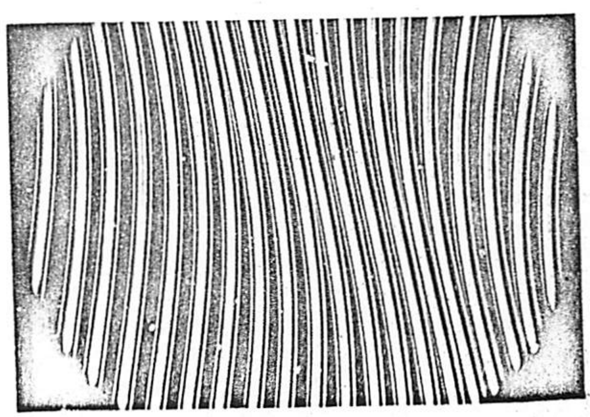

Fig. 3. Microscope groove picture of a 400-Hz signal. To show the accuracy of phase recognition, the land between grooves has been reduced to zero.

determining signal, and the necessary space conforming to the groove shown as a dashed line is created at t_3. It is more difficult to visualize the last and far more frequently found signal relationship indicated by the dash–dot line. At time t_4 a signal S_4 occurs which, although higher than S_1, requires closer groove spacing than is needed to accommodate S_1, since it utilizes the rest space provided for S_1. However, were one to reduce pitch at t_4 corresponding to the S_4 information, then the line which would connect the foot of the S_4 signal with the foot of the S_4' signal would not leave sufficient space to accommodate S_1, and must therefore be stored until S_1 has been cut and appears in Fig. 4 as the dash–dot line.

Put in a different way, in order to utilize the rest space after cutting an initial signal, the ensuing signals must be sorted according to both magnitude *and* time relationship in order to obtain a suitable pitch-control signal. Fig. 5 shows the schematic of such an arrangement. The modulation for the transfer process comes from a tape playback machine which, aside from the usual stereo playback head which supplies the modulation, also has a second playback head, called the "preview head." It is mounted on the playback machine in such a way that the preview signals LI (for left channel, inner flank) and RO (for right channel, outer flank) are displaced by exactly half a revolution from the modulation signals. The signal identified as BP (basic pitch) is a direct voltage with which the basic pitch is set. The three signals RO, LI, and BP are added at summing point 1, and an intermediate pitch-control signal IS is obtained, which must be processed according to the various signal relationships, as shown in Fig. 4 in simplified form, to obtain the real control signal PS. In comparator 2, which is equipped with a gate, the IS is compared to the actual pitch-control signal PS. If IS is smaller than PS, the gate remains open. This circuit prevents the smaller signals (like S_2 in Fig. 4) from influencing the pitch control. If IS is greater than PS, then it is fed via the subtraction stage 3, to be described later, into the sampled memory 5. It is here that the peak IS value, during 1/16 of a turntable revolution, is stored and held for exactly half a revolution of the turntable. The actual pitch-control signal PS is identical at any given moment with the largest temporarily stored IS signal. Referred to our impulse example in Fig. 4, this step ensures that control is always influenced by the highest

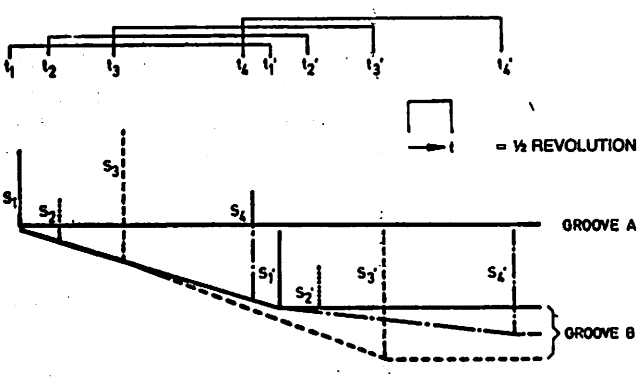

Fig. 4. Schematic presentation of two neighboring grooves with pitch control according to the rest-space utilization system. Dotted line—S_2; dashed line—S_3; dot–dash line—S_4.

instantaneous signal, here S_3. PS is furthermore fed to another sampled memory 4, which acts as an integrator and obtains the mean value of PS for half a turntable revolution, and thereby provides information about the rest space that has been created. This signal is fed to the subtracting stage 3 and provides an ever decreasing PS signal.

If one ignores the fact that we are dealing here with sampled or time-dependent processes, one can imagine that the signal fed back via integrator 4 is a feedback signal that constantly seeks to decrease the rest space.

One may ask why the seemingly constant basic pitch value BP was included in this complex control system. This becomes comprehensible when one views BP analogously to LI and RO; that is, as control signals which have the analogous task of supplying a portion of the pitch-control magnitude. In the subject circuit arrangement this is done by the computer, which means that for certain level sequences, when the rest space is to be reduced as fast as possible, the PS signal may actually become zero. This results in the carriage coming to a complete halt during the cutting process, even though a constant basic pitch was set up before the start of cutting.

Using the circuit arrangement shown in Fig. 5, the amplitude and time relationship of complex audio waves are utilized for the control of pitch. We have investigated only the horizontal component in this simplified presentation. For the lateral component of the vertical (depth) control, one basically requires a second, almost identical system. Another sampled integrator is needed for depth control. This stage, however, does not have any circuit for rest-space utilization, since depth control doesn't have any rest space in the sense in which it exists in pitch control.

By contrast to the phase recognition, the functioning of the rest-space utilization cannot be made readily visible by means of a test signal. It is typical for the microscope photos of actual musical signals to show maximum usage of available land without any improper groove kissing (Fig. 6).

4. CONTROL PANEL

Fig. 7 shows the operating panel of the machine. It has been divided into three basic sections. Starting from right to left one finds the programming section of the computer, the central indicating section, and the section in which all the operating elements have been grouped.

The main pointer instrument still shows the traditional lines per inch scale, although no longer as the main scale. The main scale is actually to be found right below and indicates in millimeters or fractional inches—the space consumed by the groove just cut. In other words, the physically proper linear value is obtained and not its reciprocal value of lines per inch.

It is a fact that the groove-to-groove spacing consists of two linear measures; the land width and the groove width. The latter is a fixed function of the groove depth. Both values may be set as basic values for the computer, even during cutting. These values are read, each on its own calibrated instrument associated with the respective conrevolution. At the time t_1 the preview head alerts the lathe that a signal S_1 will have to be cut half a revolution later (as S_1'). The pitch control therefore has to create space for it just as the diagram shows. At t_2 there follows a signal S_2 (dotted line), smaller than S_1. This can be accommodated in the rest space following S_1 without additional pitch control. One therefore has to be sure that such signals do not produce further control signals from the computer. At time t_3 there follows a signal S_3 (dashed line), which is much larger than S_1. Here, too, the relationships can be trol knob. The sum of both values corresponds at any given moment to the actual pitch which may be read on the main instrument. The lines per inch value obtained serves only as a comparison. The two further scales of the main instrument show the pitch during the TIME and FAST modes, here too as a linear measure. LEDs next to each scale show which scale should be read at any given moment. During the cutting process the LAND potentiometer assumes the function of the pitch knob of previous disk-cutting machines. The ability to adjust the land width without having to influence any other control signals represents a great simplification of the operation. The cutting engineer may wish to choose a very wide land for echo suppression, for example, only to return to very

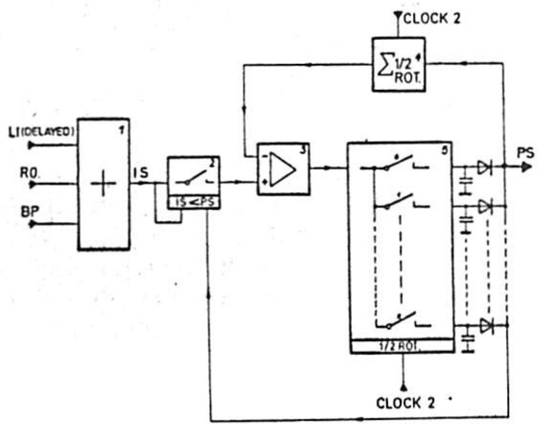

Fig. 5. Schematic block diagram for the realization of rest-space utilization according to Fig. 4. To make it easier to understand, only the lateral cut is presented. In practice, another similar circuit is needed for the lateral portion of the vertical modulation.

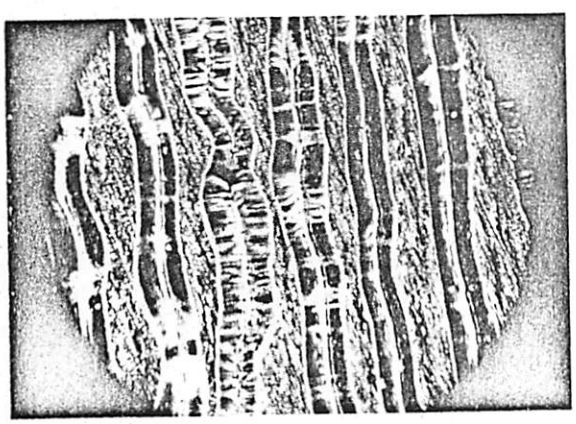

Fig. 6. Microscope groove picture of an actual sound modulation which has been cut using both phase recognition and rest-space utilization. It is typical for such pictures to show enormous packing density and the "snuggling" of adjacent grooves as far as the phase relationship permits.

narrow land dimensions right afterwards without risking an overcut. He can go down to any dimensions which the LAND instrument still indicates as a finite land width.

The groove depth will likely not be touched during the cutting process. It will be determined strictly by the computer influenced by the modulation input signal.

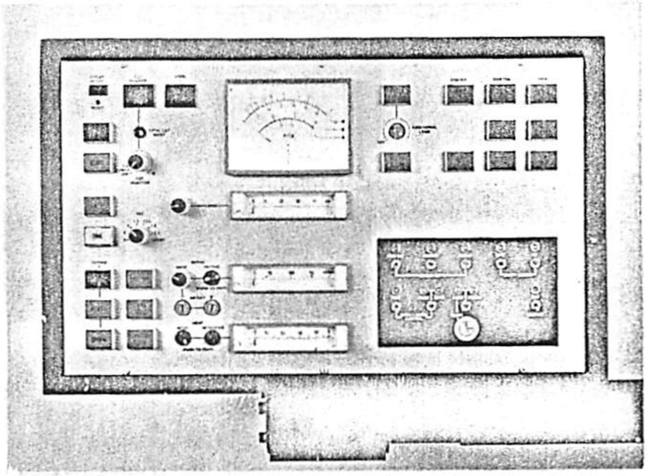

Fig. 7. Operating panel of the VMS 80 disk mastering lathe. The three meters in the center show the operation of the groove-space computer.

5. CONCLUSION

The system here described reflects the optimum analysis of the modulation to be cut on phonograph records and its conversion into signals for the control of variable pitch and depth. The extended research just completed shows a healthy respect for the methods used in the previous pitch and depth control system which has served the industry for the past twelve years. It is unlikely that with this new system the program lengths possible will be significantly greater than with the previous one, given a skilled operator. It will, however, no longer be necessary for the operator to do as much hands-on interfering with the process as he had to do until now to get the time on at the desired level. Only actual cutting experience in the field, using a wide variety of modulation, will provide the answer of just how big a step we have taken.

6. REFERENCES

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