

NEW MOTION PICTURE APPARATUS

During the Conventions of the Society, symposiums on new motion picture apparatus are held in which various manufacturers of equipment describe and demonstrate their new products and developments. Some of this equipment is described in the following pages; the remainder will be published in subsequent issues of the Journal.

TEMPERATURE CONTROLLED DISK RECORDING CUTTER*

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To attain best results in any sound system consisting of a number of elements, it is necessary to know the characteristic of any individual unit involved in the transmission chain and to make provision for proper compensation of the deficiencies inherent in that unit. Difficulties are encountered, however, as soon as such elements involved in the system do not have stable characteristics, but change, for some reason, during the time of operation. From this, it is quite evident that a high-fidelity sound-recording system requires that each element used in the recording chain must possess a definite and stable characteristic.

It has been found that a change of temperature affects the performance of two of the important elements in the recording process: one of these elements is the cutting device, and the other is the disk material. Due to the realization that temperature changes are detrimental to the proper performance control of the system, most studios (certainly the better ones) nowadays are air-conditioned to keep the temperature constant, within narrow limits, in the room where the recording is made. However, even with this precaution, difficulties present themselves, particularly with magnetic cutters which at present represent the majority of cutting devices used for high-fidelity recording. One reason for these difficulties is that a magnetic cutter converts a considerable part of the energy supplied to it into heat, causing, after a certain period of operation, a warming-up of the cutter, resulting in a change of the characteristics of the device. As a matter of fact, this internal heating of the magnetic cutter is of such importance that some cutters are deliberately constructed much more massively than is required from mechanical considerations, in order that the added metal may increase the thermal capacity of the cutter and make it possible for more heat energy to be absorbed without too greatly raising the temperature. The added metal also provides more heat radiating area.

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The purpose of this paper is to discuss in a general way the effect of temperature upon magnetic, as well as upon crystal cutting devices. The discussion will be limited to these two methods for converting electrical into mechanical energy since, to the knowledge of the writer, no other principle, to date, has been recommended for such purpose. Furthermore, it is the aim of the paper to show that a crystal cutter can be constructed which, in its performance, is rather independent of the temperature of the recording room, and is thus capable of overcoming one of the most important difficulties pointed out above.

Let us first investigate, in a more general way why cutter characteristics are dependent upon temperature. For this investigation it is very useful to distinguish between the two essential elements in every cutter; these are the damping material used in the cutter and the motor system employed to drive the cutter stylus.

To understand better the relative importance of the different components in the cutting system, it is convenient to draw a simple analogy (Fig. 1): Assuming that the chuck and the stylus are rigid and well connected to the driving system, we can visualize an electrical generator of zero impedance which represents the mechanical force. This generator has to work into the following elements connected in series: a condenser, representing the compliance (the inverse of stiffness) of the vibratory system; an inductance, representing the mass of the moving parts; a resistance, representing the internal damping; and another resistance, representing the external damping. In such a representation, the stylus motion will be equivalent to the charge. This picture, while only symbolic, will, however, explain the significance of the various components which load the mechanical displacement of the cutter.

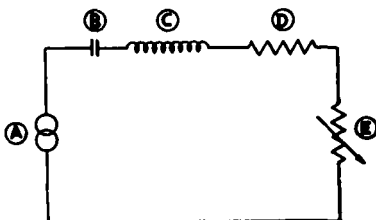


FIG. 1. Electrical analogue of representative cutter. *A*, generator. *B*, stiffness of cutter mechanism (may not be linear). *C*, mass of moving parts of cutter. *D*, internal damping (may not be linear). *E*, external damping including work done by cutting process.

Now, let us scrutinize these different components from the standpoint of stability in cutting a record. The one resistance component, which represents the energy dissipated in the cutting process, is obviously not constant. It will depend upon the depth of cut, the record material used, and other considerations. The other resistance component also, representing the internal damping material, is not constant. Oil, rubber, neoprene, koroseal, viscoloid, or other viscous materials are generally used for this internal damping. Unfortunately, it is extremely difficult, if not impossible, for the time being, to find any damping material the internal friction of which does not change with temperature, and that does not have a certain amount of hysteresis and cold-flow.

Furthermore, the stiffness represented by the condenser in many cases varies too, since the damping material may be used to some extent to increase the stiffness of the armature. In addition, these damping materials have non-linear resistive and capacitive components, and can introduce undesirable distortions.

Finally, we may arrive at the conclusion that the only stable impedance in a cutter is represented by the inductance, or the mass of the moving parts, which is not likely to change during the cutting process.

Because of all these variables it is almost impossible to expect that the performance of a cutter can be foretold. On the other hand, if we can eliminate a number of variables and make the impedance of the remaining variables small compared to the impedance of the stabilized circuit components, the performance characteristic will, in general, vary only within extremely narrow limits.

Experiments indicate that this can be done by keeping the temperature of the cutter constant, since such constant temperature will stabilize the characteristic of all the variables inside the cutter, thus leaving the external resistance component as the only variable, representing the variations due to depth of cut and differences in record material. If this remaining variable-resistance component, for the frequency range considered, is small in comparison with any of the other three components, it obviously has little control upon the characteristics of the cutter as a whole.

But let us consider certain other important aspects. Assuming that the external load due to the cutting process is negligibly small, so that for the moment it may be neglected, the next circuit element of importance is doubtless the resistance representing the damping. If this resistance happens to be non-linear—and most of the damping materials, particularly at low frequencies, are, unfortunately, non-linear—it is important that this resistance should not have a controlling influence upon the performance of the cutter, especially in the low-frequency range. For low frequencies, the cutter is stiffness-controlled, meaning that the impedance represented by the condenser in our symbolic circuit has a major controlling influence. However, if the stiffness of the cutter is to a large extent provided also by the damping material, with its non-linear characteristic, the effect of the damping will be disagreeable. Furthermore, if the ratio of stiffness to inertia of the system is such that the cutter will resonate at low frequencies where only the frictional component of the damping material exercises the necessary control, considerable distortion must be expected as a result.

This is one important reason why the designer of a good cutter must see to it that the resonance frequency of the device is as high as possible, or, to express it in other words, that the stiffness controls the cutter over as wide a range as possible; and furthermore, that this stiffness be an ideal stiffness and not change with amplitude.

It follows, therefore, coming back to our symbolic circuit, that if we can keep the stiffness of the circuit constant with respect to amplitude and also have this stiffness represent an impedance value much higher over a great part of the range than the resistive component of the damping material, we should be able to obtain an exceedingly stable cutter. These considerations led to the design of a temperature-controlled cutter, the temperature of the cutter being maintained constant within narrow limits.

A magnetic cutter consists essentially of an armature moving in a magnetic field created by a permanent magnet. This armature is connected to a chuck, and the whole moving part is thoroughly secured by damping materials. The activating coils are wound about the armature. This essential design of a magnetic cutter is shown in Fig. 2.

The magnetic motor, including the permanent magnet field and the armature is not affected by temperature variation within practical operating limits. Unfortunately, however, we must consider also the influence of the damping upon the magnetic cutter. Most of the cutters now available have the resonance fre-

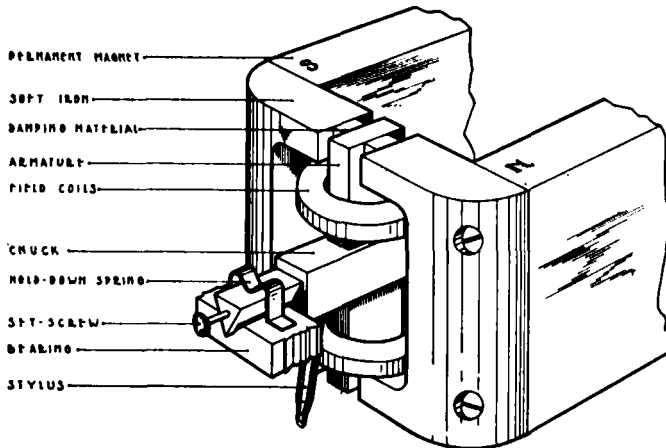


FIG. 2. Representative magnetic cutter.

quency of the system inside the useful range, particularly when the range must extend as low as 30 cycles and as high as 10,000 cycles. Since peaks should be eliminated to assure satisfactory performance, damping material must be provided that will sufficiently attenuate the resonance peak of the system. Due to the fact that the resistive component of the damping material changes with temperature, the sensitivity of the cutter, despite the fact that the motor-driving

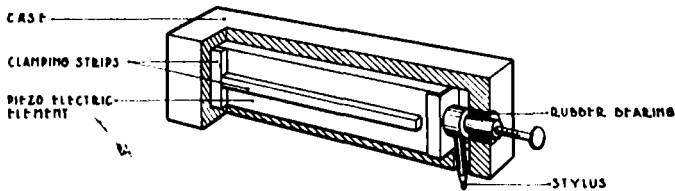


FIG. 3. Representative crystal cutter.

system is not affected by temperature change, may, in its overall performance, be subject to variations with temperature. Furthermore, due to the fact that certain amounts of hysteresis and cold-flow are present, the damping material not only acts as a resistive component, but at the same time, introduces undesirable distortion. Some control of temperature is required if best results are to be obtained from magnetic cutters.

Now consider the crystal cutter. A representative crystal cutter is shown in Fig. 3, and consists mainly of a Rochelle salt bimorph crystal element held firmly on one end to a metal case, but free to move torsionally at its other end. This free end is connected to a chuck, which may be provided with a simple bearing to move in the case, or other provision may be made to clamp the stylus rigidly to the chuck.

Electrically, the Rochelle salt crystal element which converts electrical into mechanical energy in the cutter may, to a first approximation, be considered equivalent to a condenser. Furthermore, the mechanical flexure produced by the piezoelectric effect is, within practical limits, proportional to the charge supplied to the crystal. This means that the sensitivity of the Rochelle salt element, when expressed as a ratio of flexure to electrical charge, is not a function of temperature.

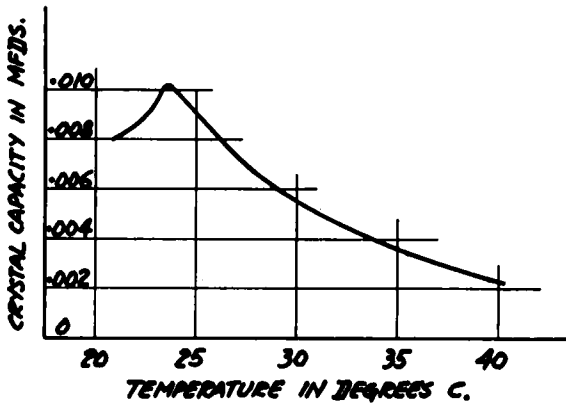


FIG. 4. Crystal cutter capacity vs. temperature.

But while it is true that the charge-flexure relation is not a function of temperature, it is, on the other hand, true that the voltage-flexure relationship is a function of temperature, and since crystal cutters are normally used in constant-voltage systems, rather than in constant-charge systems, it is unfortunate that the crystal element characteristic usually varies somewhat with temperature.

In Fig. 4, the capacity of a crystal element in such a cutter is shown as a function of temperature. The capacity is highest in the neighborhood of 23.5°C, and less at lower and higher temperatures. Since the charge is equal to the product of capacity and voltage, the sensitivity, for a given applied voltage, will be highest at this critical temperature, which is generally identified as the Curie point. From this curve, we can assume that with approximately 35°C, the sensitivity of the crystal element, referring to the same terminal voltage, will be reduced approximately 9 db. This reduction in sensitivity, so far as the cutter is concerned, is theoretical. The actual measured reduction in sensitivity of the complete cutter is less, being about 6 db between 23.5° and 35°C. These variations of sensitivity, while not objectionable, when such a cutter is used for home

recording, will be rather objectionable if it is made part of a high-fidelity sound recording channel.

As has been pointed out, the temperature effect may be eliminated by applying a constant charge to the crystal element. As a matter of fact, a circuit can be designed that will supply the cutter with a charge varying with the input voltage to the amplifier, and the simplest way of accomplishing this is to connect in series with the cutter a condenser having a capacity of the same order as, or slightly lower than, the cutter capacity. Due to the fact that now two condensers are connected in series, both of the same order of magnitude, one condenser being electrically independent of temperature, and the other somewhat de-

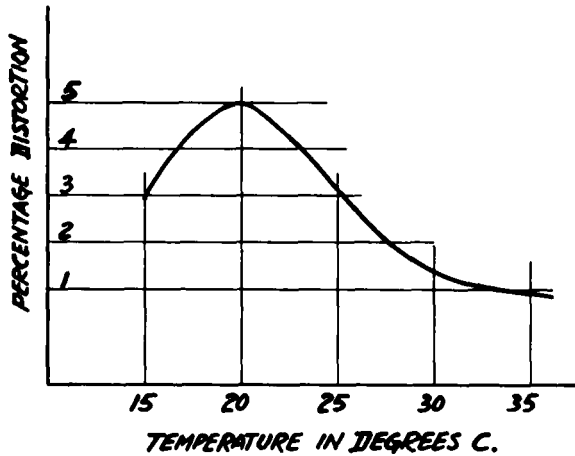


FIG. 5. Crystal cutter distortion vs. temperature.

Percentage Distortion = $100 \frac{\sqrt{E_2^2 + E_3^2}}{E_1}$ where E_1 =
 Fundamental, E_2 = 2nd Harmonic, E_3 = 3rd Harmonic.
 Amplitude, 0.7 mil; cutter voltage, 100 v; frequency,
 400 cycles.

pendent upon temperature, the electrical charge supplied to the crystal element may be kept within somewhat constant limits. While this rather simple method is useful in applications where certain leeway in stability is permitted, such a system will not provide a sufficiently constant performance characteristic to meet the high requirements of a broadcasting or recording studio. More complicated networks may be devised to provide a constant electrical charge to the cutter terminals, but it should not be forgotten that the characteristics of the damping material also change with temperature.

These points all indicate the desirability of maintaining the cutter at a fixed temperature, and proportioning the elements within the cutter for a minimum distortion at that temperature.

The question arises as to what temperature should be selected. Since air-conditioning of the recording room is a rather expensive requirement, the cutter temperature should be higher than the usual room temperature, so that the cutter performance may not be affected by variations of temperature due to climatic conditions. There are other considerations in addition to this which are of great importance. The damping material introduces distortion, as mentioned before, which distortion depends also upon the temperature. Where the design of the cutter depends greatly upon the damping material, the temperature should be chosen at which the damping material introduces a minimum of non-linearity. In the crystal cutter the damping material is not a controlling factor over the major part of the frequency range, but it has been found that the crystal element itself introduces a small amount of distortion which changes with temperature. Fig. 5 shows this distortion, the amplitude of motion being a parameter. The distortion is small at and above 35°C , and for the cutter to be described a temperature of approximately that value has been adopted for purposes of stabilization.

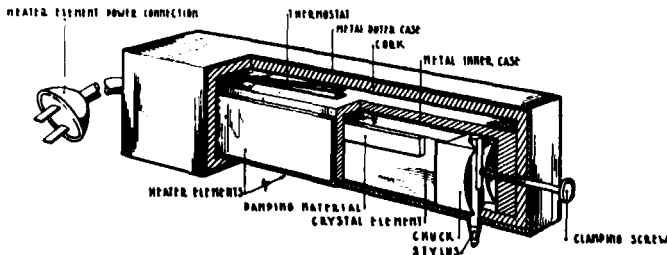


FIG. 6. Representative temperature-controlled crystal cutter.

At this point, the fact should be emphasized that the crystal element does not generate much heat in operation; nearly all the heat produced in a crystal cutter is generated by the damping material. However, experience has shown that even during long periods of operation, the temperature of a crystal cutter is not increased by the inherent damping losses, thus making it simple to stabilize the temperature of such a device.

Fig. 6 shows the assembly of a temperature-controlled cutter. A four-ply crystal element is mounted in a metal casing on koroseal pads. These koroseal pads represent the damping, and not only provide a very stiff mounting support, but, because of their damping characteristic, practically eliminate the peak of the natural frequency of the cutter. The stylus chuck is connected to one end of the crystal element. This chuck has a V-groove bent into the form of an arc, thus permitting the stylus to rest upon two points. The stylus is pressed against the V-groove by means of the set-screw mounted in the cutter casing. The axis of the set-screw is located on the neutral axis of the torsional motion of the crystal element. The set-screw does not participate in the motion of the stylus, thus eliminating the bearings usually found in other cutter designs. This construction reduces somewhat the inertia of the moving system.

The chuck, as described above, has been shaped so as to afford the stylus a long support. Experiments have indicated that many commercial styli have a tendency to break up when cutting higher frequencies if not supported over a large part of their length.

Two heating pads are mounted close to the cutter housing sidewalls, controlled by a thermostat which rests upon and has good metallic connection to the cutter housing. It is important that the thermostat and the cutter housing be connected by means of a good heat-conducting path. For simplicity, the heater coils are designed to be operated on the 110-volt line. The complete unit is enclosed in another heat-insulated metal shielding, making it unlikely that any draft or motion of air in the room will affect the temperature stabilization of the crystal cutter inside the housing.

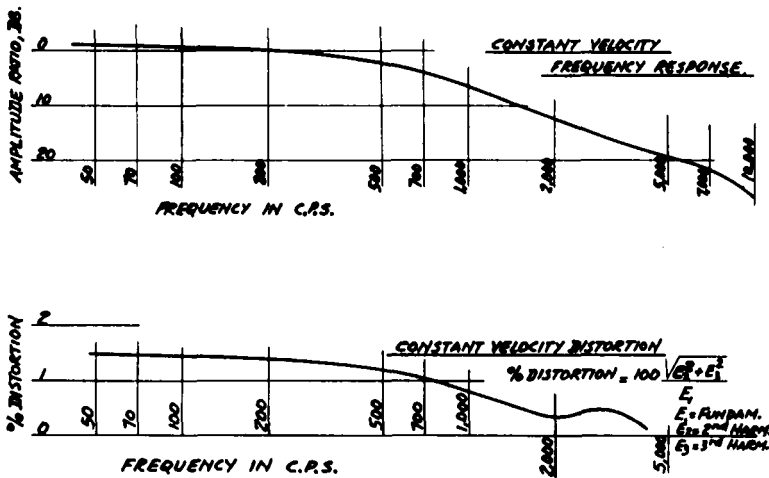


FIG. 7. Response characteristics of temperature-controlled cutter. Temperature, 35°C. Amplitude, 1 mil.

After connecting the heater system to the power supply, the temperature of the cutter will rise, and, as a matter of fact, will rise above the temperature limit set for the thermostat. A definite time is required for heat equalization, due to heat conduction, thus causing this temperature over-shooting. But soon the thermostat begins to operate and finally the cutter arrives at the proper temperature. This period of heating-up and adjusting to the proper temperature depends upon the location of the heating elements and thermostat, and the wattage for which the heater coils are wound. In the design shown, the temperature stabilization requires ten or twelve minutes. This does not mean, however, that the cutter may not be used somewhat earlier, since after five minutes the temperature variation will be sufficiently small not to influence the sensitivity of the cutter greatly. There is no danger in keeping the heater elements constantly connected to the power supply.

The question may arise as to whether the current or voltage on the heater terminals will interfere with the operation of the cutter because of the introduction of hum. So far as electrostatic influences are concerned, the cutter is completely shielded in its housing. On the other hand, electromagnetic induction can not take place in the crystal element. All experiments have proved that no hum problems are present.

In Fig. 7, the frequency response curve and the harmonic distortion of such a cutter are shown.

This cutter requires, for 1-mil amplitude, a terminal voltage of approximately 165 volts. Its capacity is 0.004 μf and, therefore, to extend the range for constant-amplitude recording to 9000 cycles, the cutter should be fed from an impedance of approximately 4000 ohms. The amplifier, under such a condition, should have available at least 8 watts of output power, but it is rather abnormal to cut with as great an amplitude as 1 mil, using a constant-amplitude recording characteristic. If a constant-velocity characteristic is desired for a turnover point of 500 cycles, the necessary output power required from the amplifier may be as low as 2 or 3 watts for satisfactory results.

Summarizing, the necessity of temperature control in the cutter design has been shown. Furthermore, it has been pointed out that it is highly desirable to provide such stiffness in the cutter construction that the mechanical resonance will be in the upper part of the useful range, and, if possible, even outside the useful range. Since the stiffness impedance will control the performance of the cutter, it is extremely important that it be a linear stiffness, and not introduce any distortion. The crystal element, as the driving motor for the cutter, approaches this desirable characteristic, while a magnetic cutter, inherently not gifted with this natural stiffness, very frequently depends upon damping material to increase the stiffness of the system. However, the stiffness obtained by means of damping material is usually not linear. Formerly, temperature control in studio installations was obtained by expensive and cumbersome air-conditioning. The cutter described has been designed to gain the same desirable effects of this temperature stability by means of a built-in heating element with thermostat control. It will make possible the construction of portable equipment which can now operate with the same stability as studio equipment. It has been a difficult task for the recording companies to make "on-location" recordings. In one case, where recordings were made in South America, the operator of the equipment was forced to burden himself with a dry-ice machine to keep the temperature during the cutting process within the required range. Such a temperature-controlled cutter as described here would do away with such difficulties.