Magnetic Tape Production and Coating Techniques

Donald F. Eldridge, *Vice President and Technical Director*

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INTRODUCTION

It is the purpose of this monograph to dispel the cloak of secrecy surrounding the manufacture of high-quality magnetic recording tape, and to provide interested users with a reasonably detailed description of the various steps used in its production. It is hoped that this will provide an increased appreciation of the specialized facilities and extreme care required to produce a truly precision magnetic tape and dispel the "aura of mystery" which has long been associated with tape production.

The techniques discussed are not secrets, but the precise combination of processes and equipment used by most manufacturers are highly proprietary. Therefore, this monograph describes the various techniques in common use, but does not attempt to comment on which methods are superior. Also, there are a few processes which are completely unique and proprietary to Memorex which cannot be revealed at this time.

Mixing and Dispersing

The first step in the production of magnetic tape is that of mixing. Its purpose is to produce an extremely uniform intermixture of the various constituents of the coating, namely oxide, resins, additives, and solvents. The solvent will not or should not remain as part of the finished coating.

This step may be carried out in one or several stages. It is most commonly accomplished in two stages; pre-mixing and dispersing. If the resin is solid or granular, it must be dissolved in a solvent. The various additives are usually mixed in at this point. The oxide may be added in several ways. It can be added all at once to the resin-solvent mixture or it may be pre-mixed with only part of the resin mixture or it may be made into a slurry with only solvent or a diluent. Once the premix is reasonably homogeneous it is ready for the final stage: dispersing.

The function of dispersing is to distribute the oxide particles uniformly throughout the resin and to provide wetting of the oxide particles by the resin. The small magnetic particles have a very strong tendency to agglomerate or form into clumps. The presence of these clumps is deleterious to performance in several ways. They produce noise and non-uniformity and if they protrude from the surface, they cause dropouts. It is also difficult for the resin to wet the particles which are on the inside of the clump so that a clump may be a weak spot in the coating. Therefore this step is one of the most important in the manufacture of tape.

In order to obtain a good dispersion, very high shear forces must be developed to separate the particles and to force the resin-solvent mixture into intimate contact with them. This is usually accomplished with the aid of solid dispersing media which are mechanically agitated. The media may be metallic or ceramic, and may be in the shape of balls, cylinders, rods, or of random shape such as in sand. Under high agitation, the media come continually into proximity and large shear forces are developed between adjacent surfaces. The oldest and most common dispersing method is a ball mill. This is simply a jar or barrel which is filled partially with the dispersing media. The mixture to be dispersed is then added and the mill rotated about its axis of symmetry. As the mill rotates the dispersing media is carried up one side of the container from whence it cascades downwards. The speed of a ball mill is rather critical because at too low a speed the dispersing media will tend to lie on the bottom and to produce no dispersing action and at too high a speed it will be carried completely around the drum by centrifugal force. There will be an optimum speed depending upon the viscosity of the mix, at which the best cascading action will occur. This and other types of dispersing mills are usually water jacketed in the larger sizes because the energy used in agitation is converted into heat. There are several dispersing mills which operate in a manner generally similar to a ball mill but use a different principle to produce the agitation. These include the Attritor, vibratory ball mill, and sand mill.

There are some mills that do not use dispersing media but instead depend upon very intense mixing to achieve high shear. These mills generally operate with a higher viscosity mix than those with dispersing media and are often used as a pre-dispersing step prior to the main dispersing step.

The time required to achieve a uniform dispersion varies rather widely, namely, from a relatively few minutes to a matter of days. It is a function of a number of factors, such as the degree of agitation, or the power input, the size, shape and density of the dispersing media, the presence or absence of wetting agents, the type of resin, the type of oxide and the viscosity and other rheological properties of the mix. Various factors are used in evaluating the point at which a good dispersion has been attained. These include color, viscosity, and power input required. Small amounts of the mix are usually drawn off at various stages of dispersion and either coated in the form of tape or in the form of a draw-down on a glass slide. The coated sample is then examined physically for presence of agglomerates with the aid of a microscope. Actual performance data may be obtained from the sample if it is coated in the form of a tape. Once a satisfactory dispersion has been achieved, the mix may either go direct to the coater or, more commonly, it may be held in a storage tank until it is required for coating. The mix may be filtered as it is pumped from the dispersing mill to the storage tank or coater to remove any agglomerates which may remain or foreign matter of any type which may be in the mix.

Storage

The length of time a mix may be held in a temporary storage tank is limited by the rate at which the oxide will either agglomerate or settle out and also by other chemical processes which may take place. Most thermosetting resins have a rather limited "shelf life" because the cross-linking reaction will often start even at room temperatures, resulting in either a viscosity increase, or at worst, complete gelling. If the mix viscosity is low and if a high degree of wetting has not been achieved, severe re-agglomeration may occur within a relatively short time. On the other hand, it is possible to achieve stable dispersions which will have shelf life of weeks or even months, just as with some modern paints. The mix is often agitated during storage. Of course, after storage for a relatively long time, the mix can be redispersed with a relatively short time in a dispersing mill and then coated. The dispersion is quite likely to be thixotropic in nature, that is, its viscosity is a function of its recent shear-force history. With this type of material care must be observed to bring it to the proper viscosity before coating.

Coating

The function of this step is to apply a very thin, uniform coating of the mix to a web of base film at a
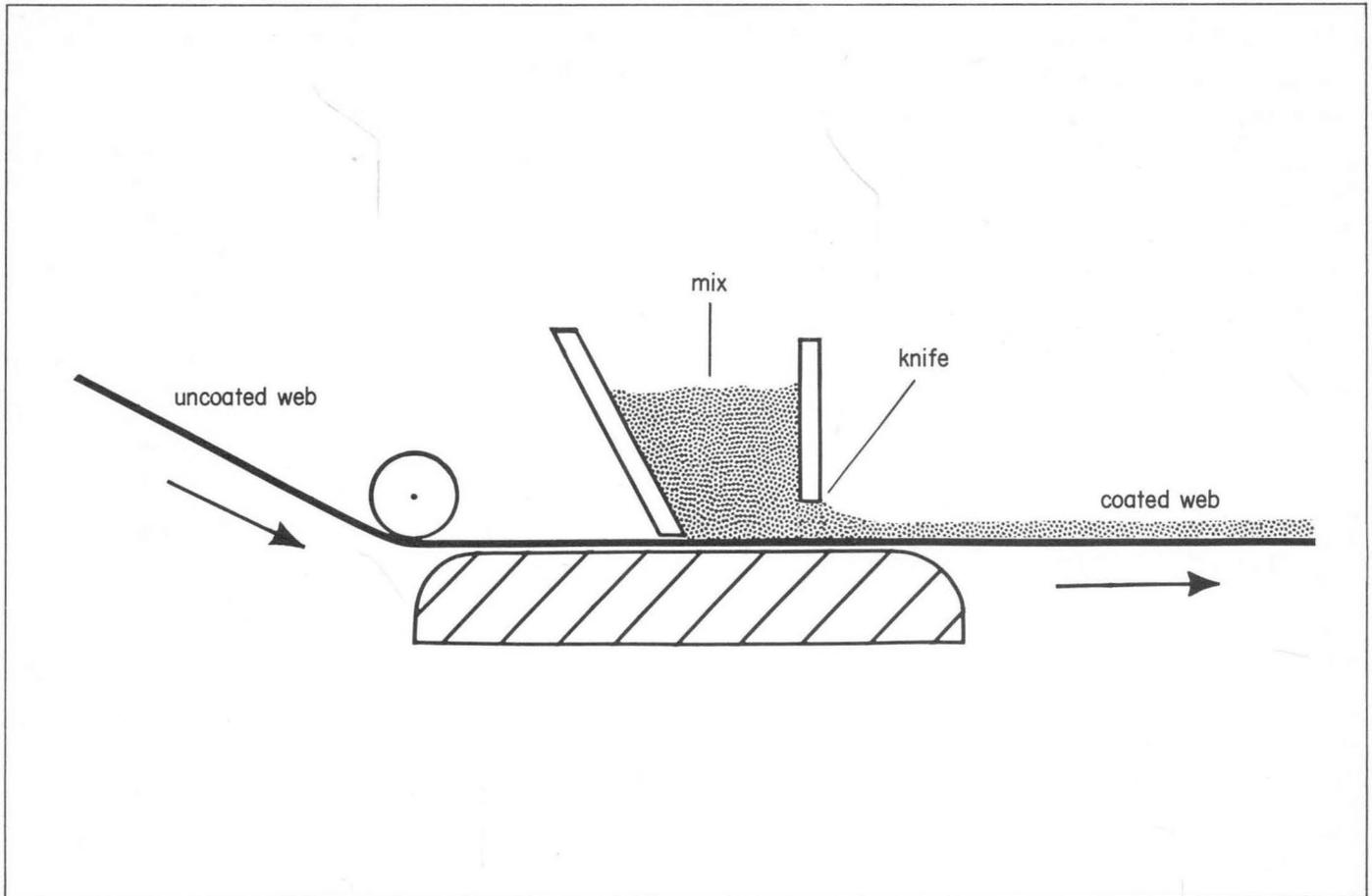
FIGURE 1. Knife Coater *The coating is metered onto the web through the gap between the "knife" and the web. Base gauge film variations, or even dirt under the web, can cause coating thickness variations.*

reasonably high speed. The key word here is uniform. If a typical coating of 0.4 mil is to have a uniformity of say $\pm 2.5\%$, the coating must be uniform within ± 10 microinches. The coating must be uniform both along the web and across the web. It should also be very smooth and not contain ridges, bumps, bubbles, pits, or craters.

The simplest and therefore perhaps the most common form of coating is knife coating. The blade of the "knife," which may be sharp or very blunt, extends across the web and forms a dam behind which is the mix. There is a small gap between the bottom of the knife and the top of the base film, which produces a metering action. Thickness will also depend on the mix viscosity and coating speed. The knife may be fixed so that the total gap through which the base film and coating move is constant, or the gap may be maintained a constant distance above the top surface of the base material. In the case where the total gap is constant, gauge variations in the base film will produce variations in the gap dimension and therefore in coating thickness. This problem is somewhat lessened but not eliminated by referencing the gap to the top surface of the base film because gauge variations which occur over short distances may not be compensated for. In fact, this problem is the major shortcoming of knife coating.

Variations in coating thickness due to variations in base film are eliminated in various types of roll coaters. Here the metering action is independent of the base film thickness. One such is a reverse roll coater. The mix is applied in a relatively thick layer to a very accurate, smooth-surfaced roll called the applicator roll. The layer of mix carried around the roll is then metered either by another roll rotating in the same direction or by a doctor blade similar to that used in knife coating. The metered mix is then transferred from the applicator roll to the base film, the surface of which is supported on one or more rolls so that the film is moving opposite to the surface of the applicator roll. The coating is thus applied in a wiping action. Although this type of coater eliminates variations in the base material, it does not eliminate all thickness variations. The size of the metering gap may vary due to imperfections in the roll bearings or doctoring knife or due to vibration or other external motion. Here, as in other types of coatings, the viscosity and other rheological properties of the mix play a very important part.

An entirely different sort of metering action is utilized in gravure coating. This type of coating is similar to that used in some types of printing presses. The surface of the gravure roll is engraved with a series of fine grooves closely spaced together. The grooves, of
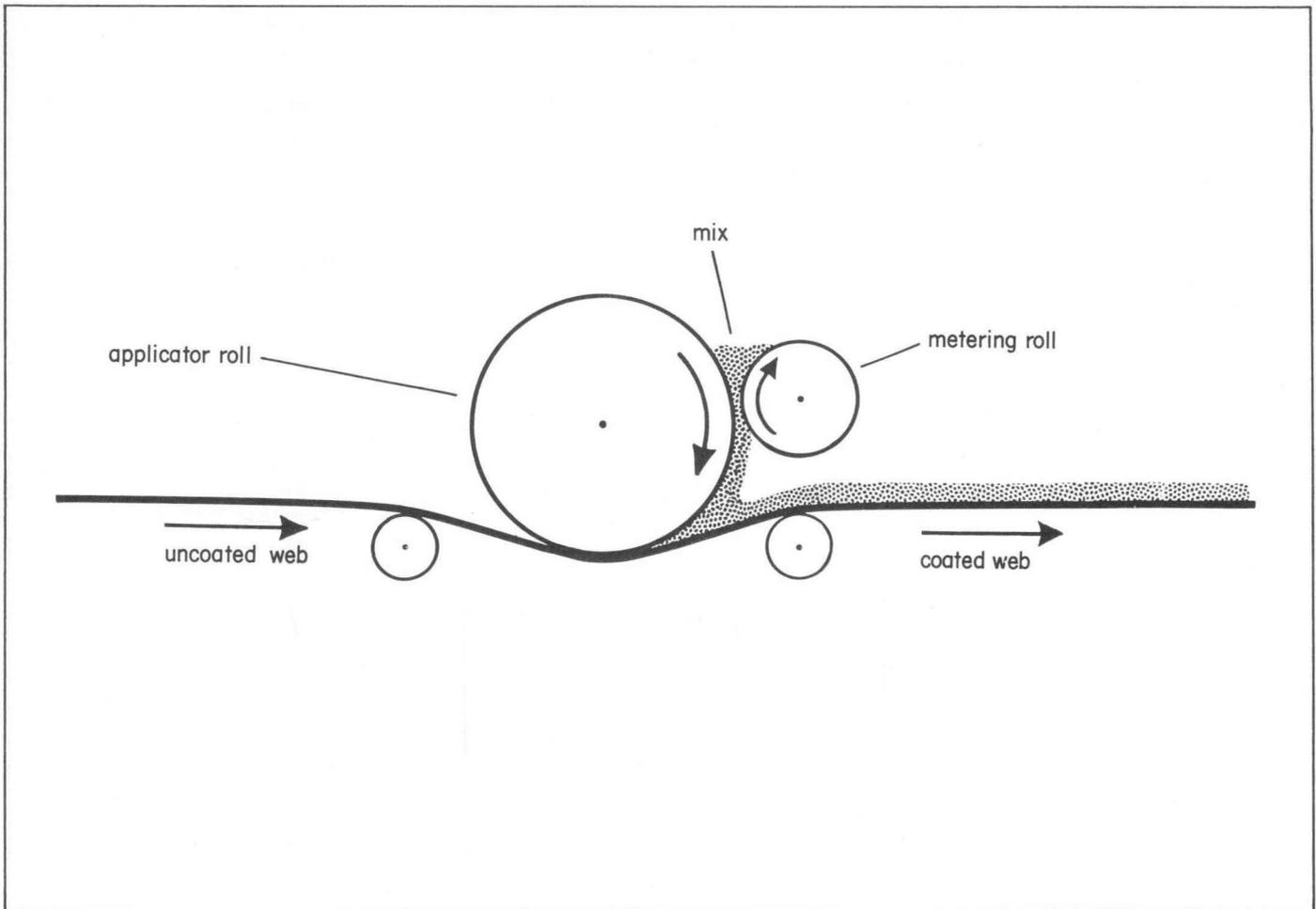
FIGURE 2. Reverse-Roll Coater *The coating thickness is determined by the gap between applicator and metering rolls. Run-out of these rolls is the major source of thickness variations.*

given shape and pitch, will pick up and hold the mix. All excess mix is then doctored off the surface of the roll so that the only material left is that contained in the grooves. Thus the metering action is produced by the size, shape and pitch of the grooves rather than by the spacing between two moving parts. The mix is finally transferred to the base material which is moving in the same direction and at the same speed as the gravure roll. If the mix has a much greater affinity for the base material than for the gravure roll, it will transfer entirely to the base material. As applied to the base material, it is of course in the form of small ridges usually running diagonally across the base material. These must be smoothed out if a truly uniform coating thickness is to be achieved. It is this smoothing that is really the major difficulty or shortcoming of the gravure coating method. If the mix can be made to have sufficiently good flow characteristics, it will flow out and level itself. However, various sorts of leveling devices may have to be used just after the coating. These may be fixed or rotating rods or other shapes which will produce a flow and shearing action. It is quite possible, however, for these leveling devices to nullify the inherently accurate metering action of the gravure coating method by themselves producing variations in coating thickness.

There are a number of other coating processes which have not found commercial application for magnetic tape. These include spray coating, dip coating, and casting the coating onto a smooth surface and then applying the base material to the back, causing the coating to adhere to the base and pull away from the smooth surface.

Orienting

Immediately after coating, while the mix is still very fluid, a magnetic field may be applied. In the case of acicular oxide particles, the individual particles will tend to rotate and align their long axes with the applied magnetic field. The degree of alignment achieved in commercial magnetic tapes is by no means ideal or complete but nonetheless considerably enhances the magnetic properties and performance of the resulting product. The magnetic field is usually applied in the direction of tape motion but may, as is the case for video tape, be applied across the tape, or at any angle. Both permanent magnets and electro-magnets are commonly used. It is important that the applied field be precisely longitudinal and not tilt towards the vertical direction such as occurs if a single bar magnet or
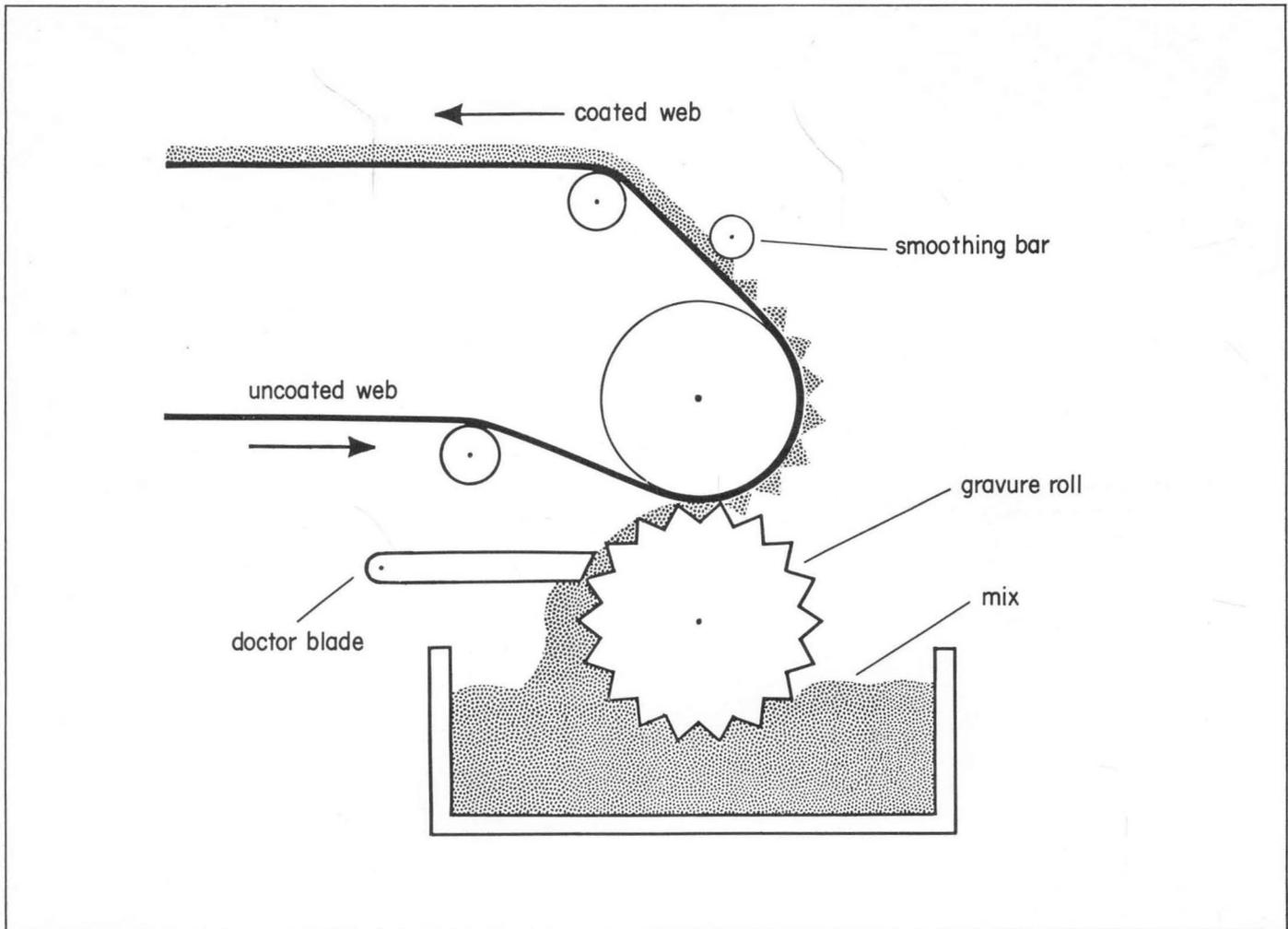
FIGURE 3. Gravure Coater *The amount of coating applied to the web is determined by size and pitch of the gravure grooves, and by the characteristics of the wet mix. Final smoothing of the pattern thus created occurs after coating. Thickness variations may occur from the smoothing action or from variations in the mix characteristics.*

horseshoe magnet is used. An imperfect longitudinal orientation which is inclined towards the perpendicular direction can produce a rather strange effect: An enhancement of the recording when the tape is played in one direction but a decrease in output when the tape is played in the reverse direction. This arises because, in one direction of play, the orientation is aligned with the trailing recording field (which is also inclined to the vertical) while in the opposite direction the orientation is opposed to the trailing recording field. This effect is particularly noticeable at short wave lengths and can be observed in some commercial tapes.

It is not possible to produce a completely unoriented tape simply by removing the orienting field. This perhaps surprising fact occurs because there is a significant amount of orientation introduced by the coating process. Most methods of coating involve some hydraulic shearing action. This is most readily visualized for the case of knife coating, where the portion of the mix adjacent to the base film is moving at the velocity of the base film and the portion adjacent to the knife has zero velocity. Thus an acicular particle which has an orientation out of the plane of the base film will

have a torque applied to it because of the differences in velocity of the fluid between its upper and lower end. This hydraulic orientation aids to a degree that being intentionally induced by the magnetic field even though the type of particle alignment produced is somewhat different. It is only undesirable if an attempt is being made to orient in some other direction or not at all.

An undesirable effect which may occur during the orienting process is that of ridging or roping. Unfortunately, when a field is applied the particles not only tend to rotate but tend to form into chains such as one commonly sees when iron filings are used to indicate a field around a permanent magnet. If too intense an orienting field is applied for too long a time, the surface of the tape may be found to have the appearance of a large number of intertwined ropes. This, of course, produces considerable roughness and increases the average spacing between the recorder heads and the tape. To avoid this effect the strength of the magnetic field, the viscosity of the mix and the degree of dispersion at the time of field application must be carefully controlled.
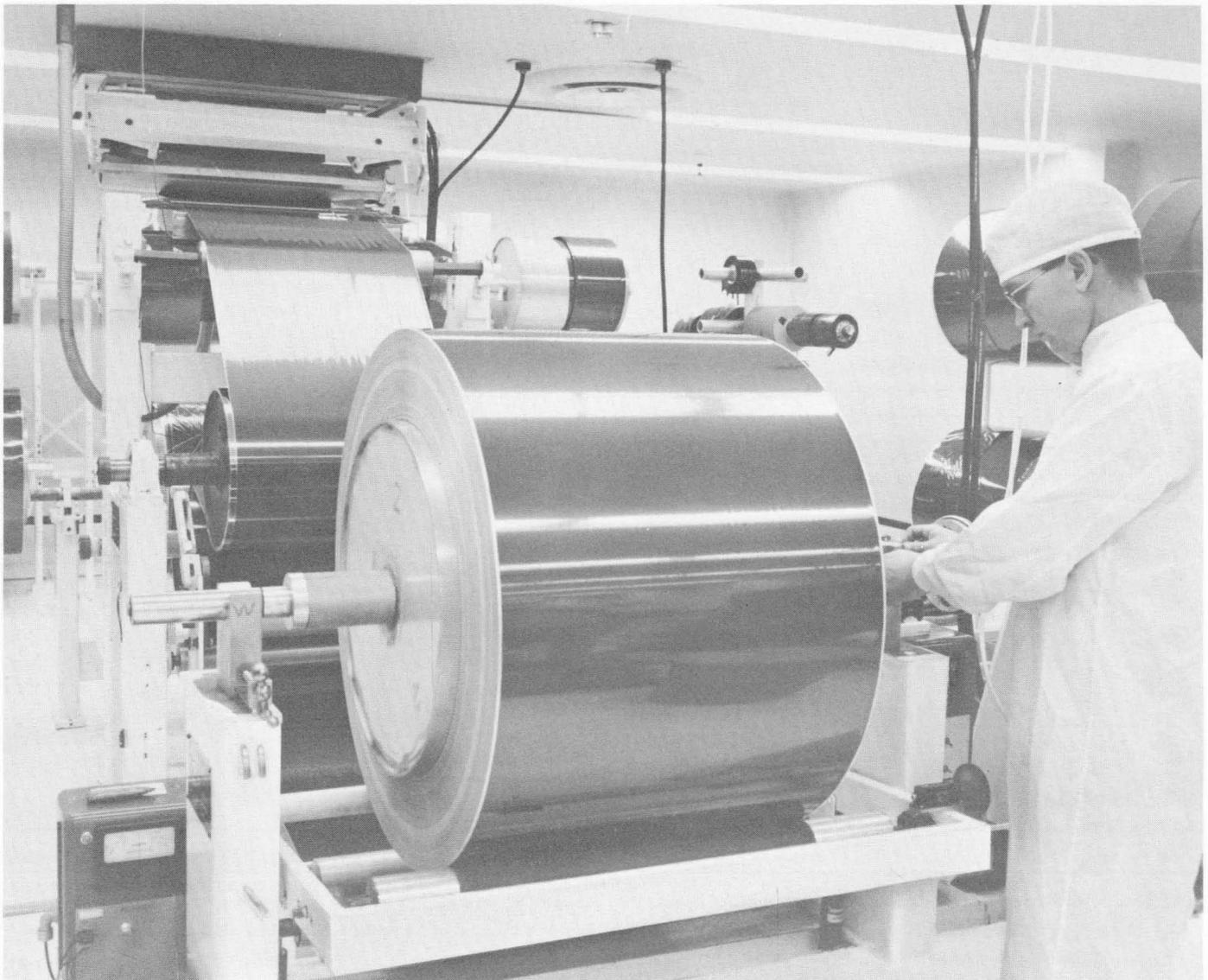
FIGURE 4. Coated Web *After leaving the curing/drying oven, the coated web is wound up under controlled tensions on large diameter drums for storage prior to slitting.*

Drying and Curing

After orienting, the solvents must be evaporated with the aid of heat and a substantial flow of air. The airflow is necessary to remove the solvents from the drying area because they are usually explosive, toxic or both. In the case of thermoplastic resin binder materials, solvent removal and drying is the only operation performed in the oven. With thermosetting resins the additional step of cross-linking or curing is necessary. The degree of cure achieved is a function both of temperature and of time, therefore temperature, length of tape in the oven and line speed are rather closely interrelated. They are also interrelated in the case of thermoplastic resins because they control the rate and degree of solvent evaporation. It is very important to achieve complete solvent removal and complete curing during this stage in the process. Otherwise, the mechanical properties of the resulting magnetic tape will change with time as additional solvent removal or curing occurs.

Surface Treatment

An optional processing step which may be included to enhance certain properties of the tape is surface treatment. The condition of the recording surface is one of the most important factors in determining overall recording performance, and quite a variety of techniques have been used in the attempt to improve upon the surface which resulted from normal processing. There is, of course, a wide variation from tape to tape in the surface that is achieved by the normal manufacturing process. The earliest and simplest surface treatment used is a burnishing, accomplished by passing the tape surface over a metal surface which may be fixed but more commonly rotates counter to the direction of tape movement. This treatment simulates what will happen during the first few plays of a tape on a recorder. It can be observed that with some tapes the short wavelength output increases several db after the first few plays. This is because a certain amount of wear has taken place which has reduced the height of

the largest projections on the surface thereby allowing more intimate contact with the head.

Another technique is calendering, wherein the tape surface is placed in contact with a highly polished metal surface under pressure, thus forcing the plastic surface to conform to the metal surface. This is accomplished by passing the tape between two rollers, one metal and one of a softer material, to control the unit pressure. The rolls may also be heated to promote flow of the binder resins.

Yet another technique is that of rubbing the surface of the tape against itself, that is, passing the tape around a loop and bringing two portions of the surface in contact with one another. This technique may produce some improvement in output, but also tends to damage the tape surface and to pull or partially pull oxide particles away from the binder material so that when the tape is placed on a recorder, a rather high degree of oxide shed may occur during the first few passes. It is also possible to treat the surface chemically to produce either selective removal of material or the addition of material.

The main goal of surface treatment is the enhancement of short wavelength performance by allowing more intimate contact between the head and tape surface. The various methods accomplish this either by removal of some of the peaks and ridges or by flattening or squashing them back into the surface. Another advantage that usually accrues with surface treatment is reduction of dropouts. This is because dropouts are usually caused by protrusions from the surface of either parts of the coating material or foreign matter. These are either removed or flattened by surface treatment. Certain deleterious effects may also occur. For instance, the life of the tape may be reduced by surface treatment. The reason for this becomes clear if one regards surface treatment merely as having the same effect as prolonged usage that the tape might have. The frictional properties of the surface will also be affected. The tendency to blocking or layer-to-layer adhesion will increase as the surface becomes smoother.

Slitting

The processes which have been described are carried out on a wide web of tape which typically ranges from six to sixty inches wide. This must then be slit to a width appropriate to its intended application. Rotary shear cutting is the slitting technique used almost universally in the manufacture of magnetic tape. Circular knives make intimate contact with one another performing a scissor-like action on the tape. The knives may be thick and extremely rigid or they may be thin and flexible. They may also be fixed rigidly to a shaft or they may be individually spring loaded. Great care is required in this step to produce tapes slit to the very high accuracy required by today's precision tape handling machines, and also to prevent damage to the edges which may occur during the cutting process. For instance, if the knives are not adequately sharp,

the action will be one of tearing rather than shearing and a ragged edge will result. This edge will be weak and will tend to wear rapidly, producing wear products which may lead to an early end of tape life. Imperfect slitting also produces debris in the form of small shreds and chips of base material and binder and oxide. These may fall onto the surface of the tape and become dropouts or they may cling to the edges becoming a source of dirt and contamination later on. To alleviate this situation various cleaning devices are often attached to the slitting machine.

Rewinding and Packaging

During slitting the tape may be wound onto the reel upon which it will be used, in which case the next operation involved is merely that of boxing. On the other hand, it may be spooled on an intermediate hub and then rewound onto the final shipping reel. In the case of computer tape, an intermediate reel or hub is usually used because most computer tape is 100% inspected on a tape handler.

The finished reel is usually demagnetized so that it will arrive at the user with no spurious information recorded on it. Prior to shipping each reel is placed in a dust-proof plastic container and sealed so that it will arrive at its destination in as nearly as possible the same condition as it left the manufacturing plant.

Inspection and Testing

Testing during manufacture falls into three categories. In-process testing, 100% inspection, and statistical sampling. The in-process testing is done during manufacture to control the manufacturing process. In-process testing may be accomplished by removing small samples from the process and testing them in the laboratory, or it may be accomplished with in-line testing instruments.

One hundred percent inspection is used on tapes for computer use which must be certified to be completely error free. This means that each reel is placed on a computer tape handler and actual recordings are made on all tracks using the same format as the computer for which it is intended. Another method is to use one or more sets of heads which record and reproduce from the entire width of the tape, so that between-track errors are detected. This method makes a single certification valid for a variety of computer formats. When an error is detected, due to a missing pulse or to a noise spike, the section of tape producing the error stops in an accessible location. An operator then attempts to remove the offending particle or protrusion and retests the same area. If the error cannot be eliminated the tape is rejected or the bad area is marked so the computer will not record on it.

Neither in-process testing nor the certification of computer tape are sufficient to guarantee that the finished tape meets all specifications. Therefore, every lot of precision tape must be subjected to a series of physical and performance tests to insure its compliance with

FIGURE 5. Computer Tape Testing *Tape for computer use is automatically 100% inspected on programmed computer tape handlers in a "white room" environment.*

manufacturers' and users' standards. In addition to lot-by-lot testing, periodic samples are selected from among production lots and given a wide range of magnetic, physical, chemical, and performance tests to guard against any long-term change or drift in processes or raw materials.

Many of the performance tests specified by government agencies, users, and manufacturers are conducted on a standard reference recorder which provides a common testing reference. This type of testing though necessary and valuable cannot always predict the performance of a tape on a different type of recorder or for a special application or under unusual environmental conditions. Therefore, in addition to tests on the standard reference recorder, tape performance must often be evaluated on the type of recorder and under operation conditions similar to those which will occur in use.

CONCLUSION

The major steps in the manufacture of magnetic tape have been discussed. Specifically described are mixing, dispersing, storage, coating, orienting, drying and curing, surface treatment, slitting, rewinding, packaging, inspection and testing. They are covered in sufficient detail to provide the user with an appreciation of the complex processes, equipment, testing and care which are required to produce premium quality magnetic tape.

One of the striking features of precision magnetic tape is that every single detail of each one of these steps must be done absolutely correctly. There is no possibility of going back and reworking as in equipment manufacture. It is this single fact which places the greatest demand on the manufacturer and which makes the production of premium quality magnetic tape one of the most exacting tasks in the world.