Considerations of Head Wear in Magnetic Recording

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The useful life of a head varies widely from a hundred hours or so to several thousand hours, depending upon the type of head, the type of transport and the type of tape. The problem of head wear is most acute in applications, such as broadband recording, where the head dimensions are small and the head-to-tape pressures and velocities are large. In such critical applications, an adequate head life can be obtained only by using tape which has been specially designed to have minimum abrasiveness. Current Memorex tapes fall into this category, being less than one tenth as abrasive as regular tapes.

A problem which faced Memorex during the development of these low-abrasion tapes, and which faces the user in selecting tapes for his application, is how to measure the abrasiveness of a tape meaningfully and quickly. The direct measure of head life is laborious and expensive. As an example, suppose a broadband head has a life expectancy of 1000 hours when operating at 120 ips. To check the life of such a head using new tape would take a total of 36, 000, 000 feet and would cost some $400, 000. The obvious shortcut of multiple plays of each reel must be used with discretion, since the abrasiveness of many tapes varies considerably with use. Ideally the number of plays should correspond with the number a reel would have in actual operation — less than ten is common in many applications.

The approach used in the Memorex laboratories was to develop a quick, absolute test of abrasiveness the results of which could be used to predict head wear; to check these predictions against observed head wear using a variety of head-tape combinations; and, finally, to use the abrasion test as a guide to the development of improved tapes which can be expected to provide exceptionally long head life.

Summary
A sensitive method has been developed to measure the abrasiveness of tapes under controlled conditions, and a large body of data has been collected using various tapes, head materials, pressures and speeds. This data can be used to predict head wear and, in all cases where it has been possible to make comparisons, predicted and observed values of head wear have been in reasonably close agreement.

It has been found that tapes differ very widely in abrasiveness. Commercial tapes vary over a 50 to 1 range and experimental tapes have been made covering a range of over 300 to 1. The demands of various applications also differ greatly; for example, a tape which may be perfectly satisfactory for computer use may be totally unsatisfactory for broadband use where it might result in a head life of less than 200 hours.

Special manufacturing techniques have been developed for the production of tapes to be used in the more critical instrumentation applications. That these techniques are successful is indicated by the fact that current Memorex broadband tapes are predicted to give head life in excess of 1500 hours, even when using the most delicate of present-day broadband heads. The abrasiveness of these tapes is as low, or lower, than that of any competitive broadband tape and is not subject to the wide variation that has been observed from roll to roll of many of the competitive tapes. Moreover, these low-abrasion characteristics are not confined to Memorex broadband tapes but are common to all Memorex instrumentation tapes.

Abrasion Measurement
Equipment
The main requirements were that the equipment should be sensitive enough to give a reading on a few hundred feet of tape, and could be used to simulate head wear under a range of accurately controlled conditions.

The method adopted consists essentially of determining the amount worn off the edge of a shim of suitable material held against a moving tape with a given force. The amount of wear is continuously measured by monitoring the output of a small reproducing head, mounted to a pivoted arm assembly, which approaches closer to the tape as the shim wears. The depth of shim that is worn off, and hence the volume of material, can be accurately calculated using the well-established spacing law governing the reproduction of a sinusoidal signal:

$$\text{Output change in db} = 54.5\, d/\lambda$$

where λ is the recorded wavelength and d is the change in separation. For example, with a recorded wavelength of 5.45 mils and a spacing change of 1 mil, the corresponding output change is 10 db. The relationship between decibel output and separation is linear; consequently output variations in db may be divided by 10 to obtain shim wear (d) in mils.

To meet the second requirement of controlling the conditions of wear, it seemed advisable to replace the conventional type of tape transport by one using a large rubber-coated capstan drive. In this way, as shown in Fig. 1, the shim can be held with a constant

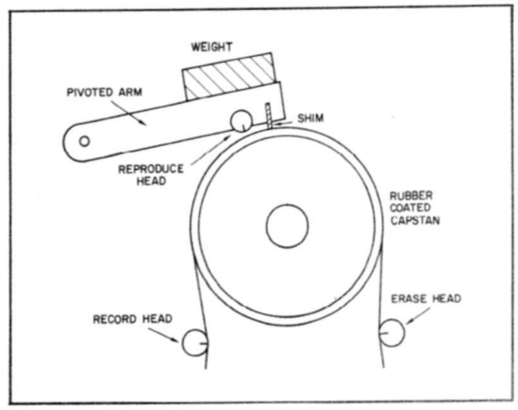

Figure 1. Diagram illustrating the principle of the abrasion measuring apparatus.

and easily measured force against the tape, and problems of controlling tension and wrap angle are avoided. The shim clamp is designed so that the shim, of width somewhat less than that of the tape, is automatically held at right angles to the tape surface. A separate precision jig is used to set the initial shim projection and ensure that the edge of the shim is parallel to the tape surface. The initial shim projection must provide a reproducing head-to-tape spacing large enough to accommodate the decrease in spacing which will occur during the wear process. Note that reproduction takes place before the wearing point to obviate the possibility of disturbance of the recorded signal by the shim. The arm assembly is precision pivoted in such a way as to reduce errors due to azimuth variations to negligible proportions.

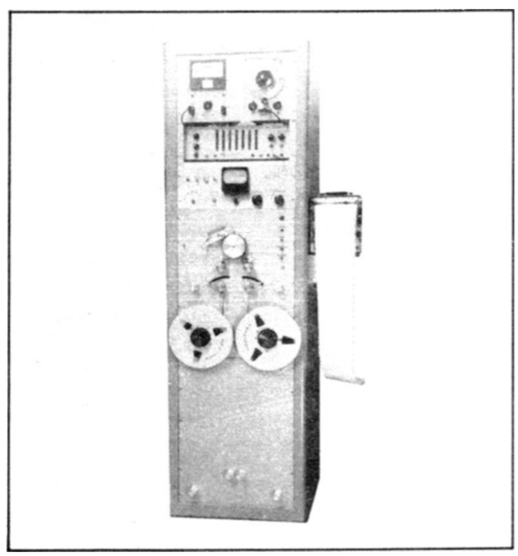

Figure 2. Abrasion measuring apparatus.

A photograph of the complete rack-mounted equipment is shown in Figure 2. Tape footage is measured by means of a magnetic pickup which monitors the rotation of the capstan and triggers the electronic counter. This counter is also used to check the frequency of the oscillator feeding the record head and make certain that the recorded wavelength is held constant. AC biased recording is used and the signal level is close to saturation. The output of the reproducing head is amplified and indicated on a VTVM to within 1% accuracy, and also displayed on a strip-chart recorder.

The equipment is normally operated on a reel-to-reel basis but provision is made for loop operation, using the guide storage system shown on the bottom panel of the rack. Loop operation is convenient for testing small, experimental samples.

Determination of Abrasiveness

Experiments confirm the supposition that the volume (V) worn off the shim is proportional to tape footage (F). Thus we can write

$$V = KF$$

where K, the abrasiveness (normally expressed in cubic mils per foot) is a function of shim-to-tape pressure and velocity, the type of tape and the material of the shim. Using the 5.45 mil wavelength, the abrasiveness is given by

$$K = \frac{A \times (\text{db output change})}{10\ F} \text{ in mil}^3/\text{ft}$$

where A is the cross-sectional area of the shim in square mils.

The test procedure is straightforward. The only precaution that deserves mention is that it may be necessary to wear in the shim, preferably using tape of the type to be tested, until a regular wear rate is established. This is particularly important when testing tapes of very low abrasiveness.

Repeatability

One important factor in establishing the validity of tests of this kind is to check the repeatability of results. One such check consisted of measuring the abrasiveness of a tape sixteen times at intervals along its length, using 100 feet for each test. The results were 2.7, 2.7, 2.6, 2.0, 2.1, 2.4, 1.7, 1.9, 2.1, 2.2, 2.1, 2.2, 2.0, 2.1, 2.1 and 2.4 decibel change in output per 100 feet. These figures correspond to a mean of 2.21, a standard deviation of 0.27 and a range of 1.0.

Effect of Speed

Figure 3 shows the way in which abrasion varies as a function of tape speed over the range 20 to 60 ips. Measurements were made at three different shim-to-tape pressures, but the results given in the figure have been normalized to 200 psi assuming a linear relationship between abrasion and pressure (see below). Based upon indications of a decrease in slope at the higher tape speeds, extrapolation above 60 ips has been carried out assuming a square root law.

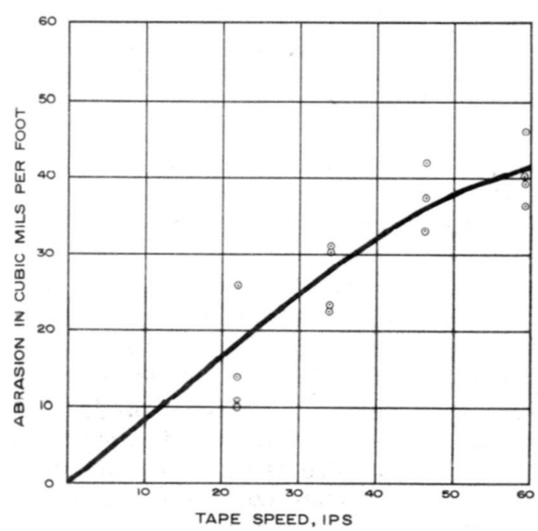

Figure 3. ***Abrasion as a function of tape speed. Data measured at 100, 150, and 200 psi, normalized to a shim-to-tape pressure of 200 psi. Experimental tapes 3 and 4.***

Effect of Pressure

Figure 4 shows the way in which abrasiveness varies with pressure over the operating range of the equipment, from 45 to 300 psi. This range is considerably above that encountered in actual tape transports, which is typically of the order of 4 psi. However, the relationship between abrasiveness and pressure appears to be sufficiently linear to warrant extrapolation down to small values of pressure.

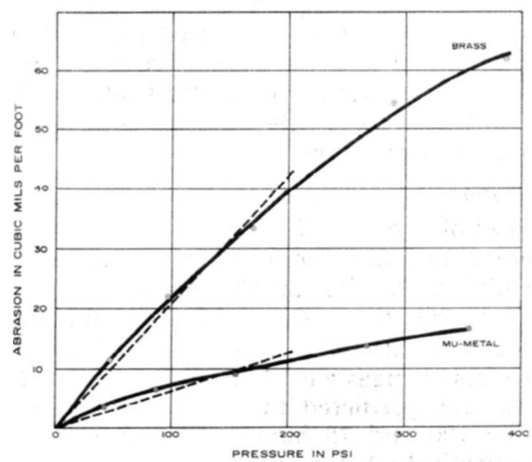

Figure 4. Abrasion as a function of shim-to-tape pressure. Tape speed 30 ips. Experimental tape 1.

Effect of Shim Material

Figure 4 also compares the relative abrasion of shims of brass and mu-metal, the two materials most commonly used in the construction of heads. The wear rate of the brass is 3 to 4 times greater than that of mu-metal, a result which is obtained regardless of the type of tape used in the test. Thus either material will rate tapes in the same order of abrasiveness, and brass shims have been chosen as the standard test material in view of their higher wear rate. Wear data has also been obtained using other shim materials, including steels, alfenol, beryllium copper and combination shims made of brass and mu-metal.

Effect of Shim Cross-Sectional Area

Experiments were made using brass shims having cross-sections of 1,000, 2,000 and 2,500 square mils, using a 0.25 lb. force. As expected, the wear rate was found to be inversely proportional to the cross-sectional area of the sample. A nominal cross-sectional area of 2,000 square mils was chosen as the standard for the remainder of the tests.

Comparisons of Predicted and Observed Head Wear

Method of Calculation

The end of the useful life of a head normally occurs when the tape wears through the depth of the gap, and the gap "opens up." The calculation of head life or, more generally, the calculation of a given degree of head wear, involves the following steps:

1) A detailed knowledge of the head materials and

geometry (including gap depth) and the angle of wrap, operating tension and tape speed of the transport on which it is mounted.

2) Calculation of the head-to-tape pressure from the angle of wrap, tension and the mean contour of the head, averaged over its life, and the calculation of the volume of material that must be removed to reach a given degree of head wear.

3) Extrapolation or interpolation of the abrasion data obtained on the tape of interest, to predict the wear rate that corresponds to the actual head-to-tape pressure and speed.

Compensation must also be made in using brass wear characteristics to predict head wear when real heads are a composition of at least two materials — usually mu-metal or hi-mu 80 and brass or aluminum. Many tests were carried out to establish a valid conversion between composite wear rates of brass and mu-metal to brass alone.

Comparisons of Head Life

Two types of broadband heads were life tested, both from major head manufacturers, on a broadband transport at 60 ips. To minimize the time and tape footage required to run the tests, moderately abrasive tape was used. Due attention was given to the fact that abrasiveness changes with tape usage. On head A the measured and predicted values of head life were respectively 100 and 78 hours; on head B the values were respectively 134 and 160 hours. In view of the various assumptions made, the agreement here is reasonably good.

A similar life test was conducted on a set of computer heads mounted on a digital transport. In this case a highly abrasive experimental tape was used to reduce the life of these ordinarily long-life heads. The tape was run continuously by the head assembly at a tape speed of 150 ips. The heads had a measured life of 128 hours and a calculated life of 137 hours.

Comparisons of Head Wear

The head-life comparisons were based upon the use of very abrasive tapes. It could be argued that quite different comparative results might be obtained using tapes of more practical type. Consequently, some experiments **were** made in which a dummy head, conforming in all important respects to a conventional broadband head, was abraded by tapes in the medium-to-low abrasiveness category. The dummy head was mounted on a broadband recorder, and was provided with reference surfaces so that the depth worn off the abraded region could be measured within a few microinches. Even so, many 120 ips passes of a full roll had to be made before an accurate measure of wear could be obtained.

The results of these experiments show that:

1) The head wear measurements rank tapes in the same order as measurements made on the abrasion tester.

2) Head wear, as predicted from shim abrasion data, is never significantly greater than measured head wear and is usually appreciably less, particularly when using tapes of very low abrasiveness. In other words, predictions based upon shim abrasion data can be expected to err on the side of safety.

Comparison of Tapes

Measurements have been carried out on a large number of different tapes, including competitive tapes of all categories. The results obtained are listed in the table below:

Class of Tape	Abrasiveness, cubic mils of brass/ft		
	Low	High	Mean
COMPUTER			
Competitive tapes	3.6	20.0	12.4
Memorex Types 22 and 24	3.0	6.0	4.5
INSTRUMENTATION AND HIGH RESOLUTION			
Competitive tapes	1.23	12.3	6.5
Memorex Types 32 and 42	—	less than 0. 5	—
BROADBAND			
Competitive (one mfg. only)	less than 0.5	6.25	—
Memorex Types 60 and 62	—	less than 0.5	—

All the tapes listed in the table are made from gamma ferric oxide particles of conventional size and shape, and there is no great variation in the density with which the oxide is packed into the coating. In view of this, it may seem remarkable that the precise way in which the abrasive oxide material is held in the binder can have such a tremendous effect on abrasiveness. However, once certain of the factors governing abrasion are properly understood, it is possible to produce experimental tapes covering a range of abrasiveness of more than 300 to 1, from tapes rivalling polishing tape to tapes which can, for most purposes, be classed as non-abrasive.

The results listed for the Memorex tapes were all obtained on fresh, unused rolls. In general it is found that abrasiveness tends to decrease with the number of times a tape is played over either the abrasion measuring apparatus or a conventional tape transport. The decrease is pronounced in the case of highly abrasive tapes, but is small in the case of tapes having an initially low abrasiveness.

All Memorex instrumentation tapes are currently manufactured using techniques which lead to an exceptionally low value of abrasiveness. The precise value is, in fact, difficult to measure with the existing equipment, even by using samples several thousand feet in length. It can be stated with complete certainty, however, that the abrasiveness is consistently less than 0.5 cubic mils of brass per foot.

This corresponds to a minimum predicted head life, based upon 120 ips operation on a typical broadband recorder, of approximately 1500 hours. The probable head life is considerably greater than 1500 hours.

The result given for the Memorex products is based upon a large number of routine Quality Assurance tests, during the course of which no sample of tape gave a measured abrasiveness in excess of 0.5 cubic mils/ft. The results given for the major competitive product were based on tests run on several different rolls of broadband tape, and indicate a considerable range in performance.