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Evaluating Performance of Digital Magnetic Tape

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by J. Mandle

ABSTRACT

Digital magnetic tape is a precisely and uniformly specified product in those areas of dimensional configuration, physical strength and magnetic properties. Not so well defined or understood are the equally important operational characteristics of wear resistance and expected useful life. Present methods and specifications for the evaluation of magnetic tape do not adequately cover dynamic performance. Specifically, the evaluation of the wear resistance of digital magnetic tape presently stresses quantitative limits of drop-out frequency. This Monograph considers the shortcomings of this approach and proposes a definition of two important performance parameters — Durability and Drop-Out Activity. Methods of testing and displaying results of tape evaluations are given as well as the basis for the assumptions and preference associated with its use.

INTRODUCTION

A great performance breakthrough has been experienced in recent years by the user of digital magnetic tape as a result of improved materials, tighter tape manufacturing process control, and the resulting higher quality of the finished product. Progress has been made to preserve these advances by more complete specifications released through equipment manufacturers, the government agencies, and the users themselves. The present computer design sophistication, however, is taxing these quality gains and is also requiring even greater tape performance in order to realize the full potential of computational capability. Higher bit densities, faster tape speeds, and more extensive tape utilization, have brought to light a need for a clearer definition of yet another attribute of a precision digital tape: drop-out resistance.

Memorex, in developing MRX III to satisfy the latest computer needs, defined this attribute in quantitative terms, and set up methods to test for it. Using this criteria along with a quantity of other requirements, Memorex developed, tested, and produced the magnetic tape which it also found highest in drop-out resistance.

In addition to this approach, laboratory findings were closely compared with field reports of samples placed to provide as taxing a cross section of uses and users of precision digital magnetic tape as are available today. With this resulting confirmation and theoretical support, Memorex recommends the Durability and Drop-Out Activity approach to tape ranking for user application in his own facility to meet evaluation requirements.

This Monograph explains the testing philosophy for drop-out resistance, describes the tests used to evaluate tapes, and points out some of the more significant variables which affect accuracy and reproducibility.

In addition, the Monograph shows a novel method of presenting test data such that tapes may be analyzed for dynamic performance characteristics with a high degree of consistent interpretation.

Tape Performance Parameters

Major consideration, when evaluating magnetic tape, is given to performance characteristics roughly grouped into static and dynamic categories. This grouping is natural in that static characteristics are evaluated independent of the tape transport system. Conversely, dynamic characteristics are tape transport sensitive and depend upon actual use environment for realistic measurement.

Static Performance

Static characteristic data is found almost universally in manufacturers' literature as well as federal purchasing specifications and commercial procurement documents. Such fundamental data as tape width, overall length, backing and coating thickness, straightness, backing material and physical strength properties are typical. Definition, plus the tolerance of these properties, insure compatibility between tape transports as well as set nominal design criteria for new tape handling equipment. It is a safe assumption that as the state-of-the-art of tape handlers is advanced, these factors will still remain essentially constant for considerable time in order to avoid obsolescence of existing tape libraries and to insure future tape interchange between existing and new computer systems.

Another category of the static characteristics class is the measurement associated with the fundamental magnetic properties of the recording media. Fortunately, within broad limits, these magnetic characteristics are compatible with the present requirements of the digital recording art. Their measurement is more often one of specification checking rather than an operational requirement. In the future, however, recording techniques may require a complete review of the measurement and control of these parameters.

Dynamic Performance

Even less standardization or universally accepted definition is associated with the dynamic characteristics of digital magnetic tape. Now the interface between the tape and tape transport impose operational restrictions which are uniquely related. Such fundamental criteria as bit density, tape speed and track format establish a very restrictive set of tape dynamic performance characteristics. These relate to specific requirements for pulse height, pulse width, start-stop distance capability, allowable signal loss per drop-out, and allowable dynamic skew error. There is evidence that the same concern shown for static characteristics is now being directed toward this more complex area of uniform dynamic evaluation.

Operational Performance

An area still remains after these requirements are satisfied by the manufacturer, and involves the serious problem of evaluating tape performance as the end user will experience it. A set of tape specifications which does not take into account the operational requirements of many transports, has little value in real life. This being the case, the tape manufacturer is faced with either testing his product on all available transports, or defining tests and conditions which will simulate the highest stresses likely to be found under operating conditions.

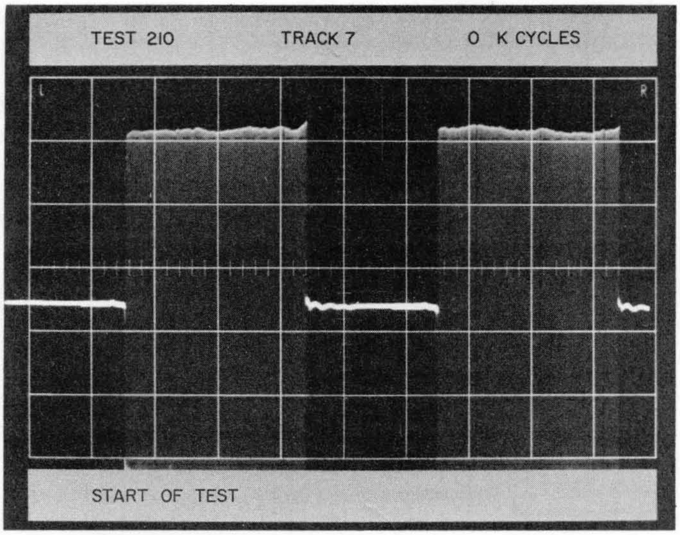
Memorex has taken the latter approach which has culminated in a performance characteristic denoted as DDA for Durability-Drop-Out Activity ratio. With this concept, contemporary digital tapes were evaluated and rated. Based on these findings, a specification was established for a new product, which, after continued exploration, resulted in MRX III, an ultra-durable precision magnetic tape with a DDA ratio 3 times that of its predecessors.

DDA expresses two measurable characteristics of a computer tape which are important dynamically and are transport sensitive. They express the resistance of the magnetic tape to producing drop-out causing wear products. This drop-out resistance manifests itself in providing a longer wearing, cleaner running, and less machine sensitive tape. Neither Durability nor Drop-Out Activity alone can effectively measure tape performance, but in combination they reveal the tape's capability under two important modes of operational stress.

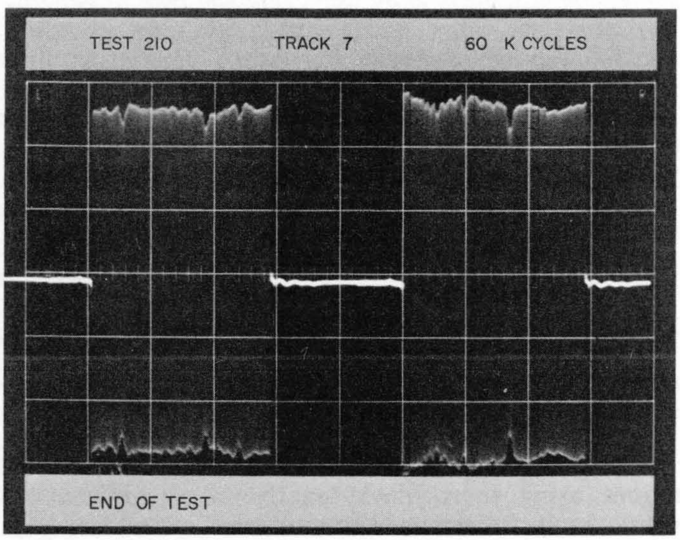
Durability is defined as the ability of the tape, expressed in terms of total tape motion across the reproduce head, to withstand a read failure when subjected to an environment designed to induce self generated wear products. Expressed another way: what ability does the tape have in either resisting the generation of wear products or self dissipating its wear products? This resistance is considered without recourse to tape path cleaning devices or distribution of the debris throughout the transport.

Durability, then, is important where transport action and tape surface characteristics will provide sufficient collection of debris and contact pressure to cement particles to the recording surface of the tape. This is the most common type of permanent tape performance failure (*Figure 1*).

Drop-out Activity, expressed in accumulated drop-outs for a specified test duration, is defined as the measure of a tape to resist the generation of migratory wear products when operated in an environment designed to provide a maximum of tape guiding surface contact. Again, the emphasis is on measuring the resistance of the tape in generating wear products. However, in this measurement, "a rate of change with use" effect is of interest. It differs from durability in that a normal, transient error rate is observed rather than the point of catastrophic failure. The incidence of drop-outs can be monitored from the certified "as received" condition through the equivalent of several months' average use.



New block *New block*



Permanent error from debris after 60 KHF.

Figure 1. 6" Shuttle test—1000 bits per block.

Measuring Operational Performance Parameters Testing Considerations

There is no universally accepted test device, procedure, or specification which relates to the wear resistance of digital magnetic tape. At present, the extension of error free tape performance is based on a result of quality certification, and estimated on performance after continued use. This approach results in statements as to the maximum number of catastrophic failures to be expected after specified usage. The difficulty in assigning discrete error values to digital tape for specification purposes, lies in the limitation of adequately describing the testing device.

Dynamic testing is machine sensitive. Very basic differences in machine design which influence tape wear may be classified generally as follows:

Active Elements

Moving	*Guiding*
Pinch Roller	Fixed Guides
Vacuum Capstan	Roller Guides
Pressure Capstan	Air Bearings
Friction Capstan	Spring Guides
Tape Speed	Packer Arms
Tape Tension	Cleaning Devices

Passive Elements

Storing	*Support*
Vacuum Chamber	Length of:
Roller Arms	Oxide Contact
Bins	Backing Contact
Storage Pockets	Edge Contact
	Headwrap

Associated with each of these elements are the materials of construction and surface finishes. In analyzing the contribution of these factors to tape wear and resultant error generation, major causes were found to be high unit pressure, long sliding support surfaces, and edge constraints. Each tape transport in volume use today has some elements of design which induce tape wear. The quantity of these elements present in any one transport has a great effect on recurrent error troubles.

A further consideration which places doubt on the value of the discrete error rating system is the electrical and mechanical differences which may not be defined by a given specification. For example, an error may be classed by an arbitrary definition, a bit error, a byte or character error, an error of a block of N characters which fails a parity check, or re-occurrence of any of these individual error classes when machine re-tries a given number of times fails to remove the error. Naturally then, a bad block of 1000 characters in a nine channel system could be interpreted to have:

288 bit errors
36 character (byte) errors
1 block error
0 errors after re-try,

depending on the initial interpretation of an "error."

Mechanical differences related to machine adjustment and part tolerances are also of major consideration. To examine this situation, a manufacturer of tape transports tested the same reel of tape to failure on ten production transports considered to be representative of normal release quality. He then tested 10 reels of the same type of tape on one transport and again ran the tapes to the same failure point. Surprisingly, the standard deviation in passes to failure between 10 transports was four times the standard deviation between 10 tapes. This result was attributed to normally acceptable transport mechanical differences which had not affected the operational quality of previous computer systems.

A testing program for dynamic evaluation of tape, therefore, should be designed to minimize the effects of normal differences occurring within transports. The philosophy used with DDA evaluation is based upon the selection of the tape movement to remove the interference of unrelated transport effects, the selection of the most severe conditions to accelerate the appearance of wear effects, and the use of grouped testing to relate test results to short periods of transport use. In addition, the test program is based upon relative results rather than numerical error expectation, thereby eliminating the need for an absolute error definition.

Standard Test Methods

The test conditions required for Durability and Drop-Out Activity evaluation are quite different. In the case of durability, the selection of the tape movement and the means of detecting a permanent drop-out primarily govern the length of time required for an evaluation. The tape movement should be selected to capture the wear products within the reproduce area of the magnetic head. This should provide maximum opportunity for high unit pressure to inbed the generated debris in the shortest time and cause a permanent drop-out. The detection of a permanent drop-out is accomplished by observing longitudinal block parity errors on as few blocks as convenient. A permanent error then is considered to exist when a fixed number of consecutive parity errors are detected in any one block.

The test for durability used by Memorex consists of a six-inch shuttle across the read-write head of two 1000 character blocks containing all "1's." The two blocks are written and read during each forward pass of the tape, and a running total of parity errors for 100 passes are examined after each pass. The number of passes is recorded and the test terminated when 100 consecutive parity errors are detected. The short shuttle keeps the tape within the immediate head region and prevents the generated debris from becoming dispersed throughout the transport, reels, and guides.

This operational approach has the advantage of providing compatibility with data processing techniques as well as giving visual evidence of the tape surface condition for very small sample lengths. For example, one 2450 foot reel of control tape is used to supply 250 test samples. These control samples are interspersed with the normal evaluation tests. They are a vital part of the test program and are used to monitor mechanical changes which continually take place in the tape transport due to adjustment and part replacements. Further evidence of the mechanical variability of the transport can be seen in *Figure 2*, showing the spread in tests for durability of the same standard over a 3-month period.

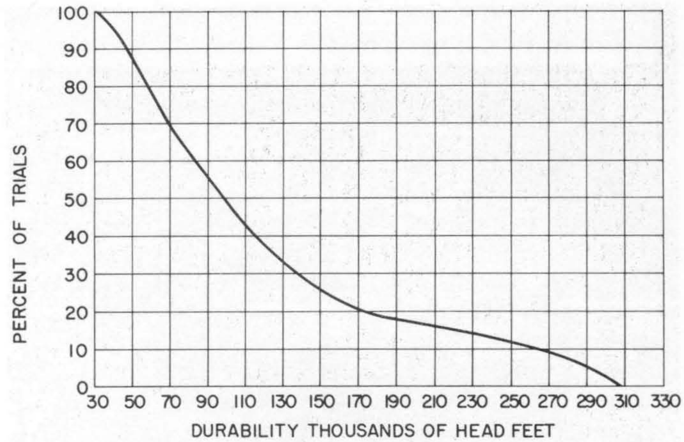


Figure 2. Durability variation as a function of trials. Control tape durability measured on the same transport during a 3 months interval.

The Drop-Out Activity test is designed differently. Here, the emphasis is on detecting the rate of generation of debris. Thus, great care is taken to provide a controllable environment for debris generation and means for detecting debris caused drop-outs. The digital transport used should provide excellent reel speed and tension regulation. At the same time, long tape paths, pinch roller actuation, and some fixed as well as rotary edge guides are desirable. The configuration used for testing drop-out activity is a 300 foot shuttle consisting of continuous writing and reading of all "1's" throughout the length of the tape in the forward pass. The tape is subjected to normal rewind and the forward pass repeated a minimum of 85 and a maximum of 150 passes. Character errors and passes are accumulated throughout the test.

This test is also adaptable to data processing techniques using short block lengths in an alternating overlapping pattern to utilize untested inter-block gap areas. As the block length is reduced, the quantity of data and the observation of actual debris location and build up will be more significant. The length of the tape shuttle was chosen because of the speed of the transport used which allowed a timed two-minute cycle. This length also is advantageous since it closely approximates metric tape lengths prescribed in international specifications for tape performance. The number of passes was chosen to insure, with high probability, the generation of some wear products in quality tape products, and at the same time, be less wear than would generate permanent errors in the poorer, less durable digital tapes.[1]

There are important conditions which are common to both testing procedures. The variable nature of test environment is cancelled out to a great degree by only comparing results of tests conducted during short test spans. Under laboratory conditions, it was found universally true that standard tapes, tested repeatedly, ranked in the same order and by the same relative proportion even though their individual quantative

[1] *NASA Specification Ref. 1*

errors varied by as much as a factor of 2 over a 4-week period of testing. The change in Durability and Drop-Out Activity data was gradual and coincided with either environmental, mechanical, maintenance, or operator changes. It is, therefore, necessary to run the tests in batteries of 3 or 4 tapes during a short time interval and include the test of a known tape as a relatable reference for ranking purposes.

Of almost equal importance is technique. Major concern with cleanliness, procedures, and operator consistency should be given if the ranking of nearly equivalent tapes are required. The debris from one tape left in guide crevices or on chamber walls may easily affect the following tape by falsely causing a high drop-out activity. Whatever conditions are used for testing, they must be controllable and consistent for reliable results.

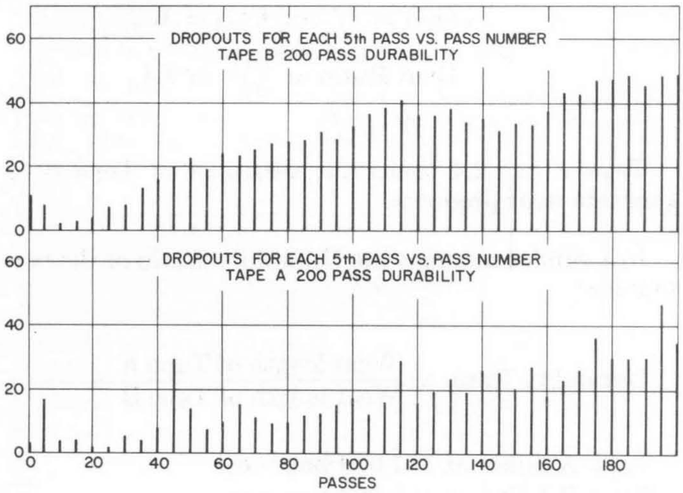


Figure 3. Full reel pass durability plot — old method. Total wear length equivalent to 500 KHF.

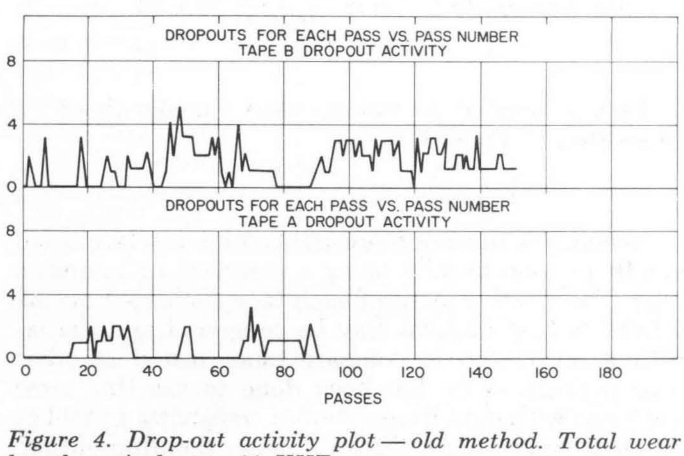


Figure 4. Drop-out activity plot — old method. Total wear length equivalent to 90 KHF.

Displaying Operational Performance Results for Analysis

After having defined the characteristic to be used for tape evaluation and specified the testing approach, it is necessary to display the resulting data in a form readily understandable to scientific personnel responsible for interpretation. The data recorded from tests consists of: a) Drop-out counts associated with any pass for Drop-Out Activity; and b) The pass count associated with the first permanent drop-out, for Durability.

Figures 3 and 4 are presentation approaches previously used to compare the performance of two tapes for the two test conditions. In all cases, the drop-out errors are character errors and are plotted as a function of the quantity occurring during past sets. This type of presentation is of little value for comparative evaluation of tape performance. Shortcomings in this approach were recognized, and the following innovations were introduced.

The term "passes" is actually not quantitative unless the length of the tape used in the shuttle is given. In addition, the pass or shuttle should be further qualified to account for the actual head to tape contact length associated with the particular transport used for the test. The term "head-feet" is defined as the cumulative wear length of tape having contacted the reproduce head during any test sequence. For instance, a six-inch shuttle test accumulates one head-foot per pass — six inches in the forward direction plus six inches in reverse. A full reel test, including a non-head contact high speed rewind, accumulates 2500 head-feet per pass after each forward pass. Ten full reel passes then equal 25,000 head-feet. With broad interpretation to be examined later, 2500 six-inch shuttles are the equivalent in "wear products" generated to one full reel pass.

The data is plotted as cumulative variables on log-log paper. The increasing values of drop-outs and head-feet will always produce a positive function, and the power law relationship of these variables is represented by a straight line. The interpretation of the slope and discontinuities of the accumulation of wear product drop-outs with head-feet is accomplished by inspection.

As a saving in point-by-point plotting, DDA uses just three data points to represent the tape wear performance. These points are: *(See Figure 5)*

1) The number of head-feet accumulated when the first drop-out is detected as Drop-Out Activity.

2) The number of cumulative drop-outs which have occurred as the wear length equals 50,000 head-feet.

3) The number of head-feet accumulated when the first permanent error occurred.

A straight line is drawn joining these three points. At the point of durability head-feet, the line is drawn with a discontinuity of greater slope, signifying accelerated drop-out count due to the catastrophic failure of the tape.

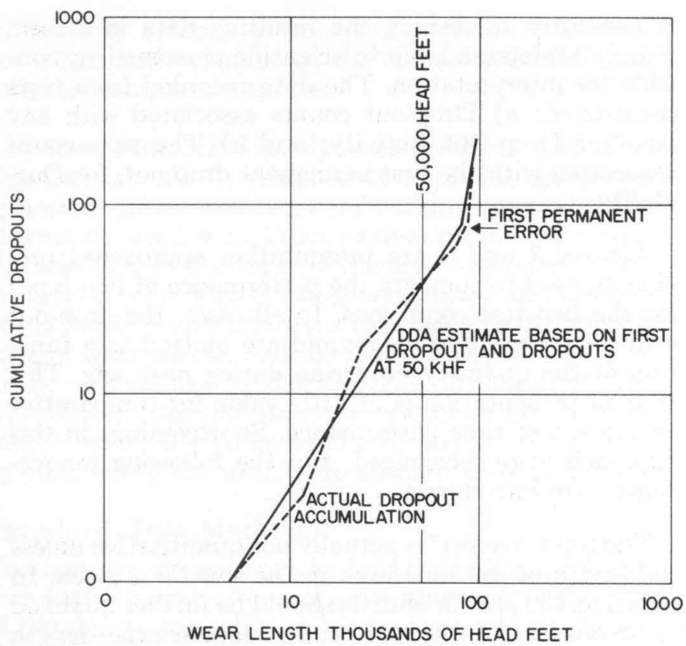


Figure 5. Drop-out accumulation vs. wear length. Durability, Drop-out Activity three point estimation vs. point by point plot.

Figure 6 represents the same information shown previously in *Figure 4*. The numbers beside the straight runs indicate the cumulative drop-outs. The value at the knee represents the total number of head-feet of wear logged when the tape failed due to a permanent error.

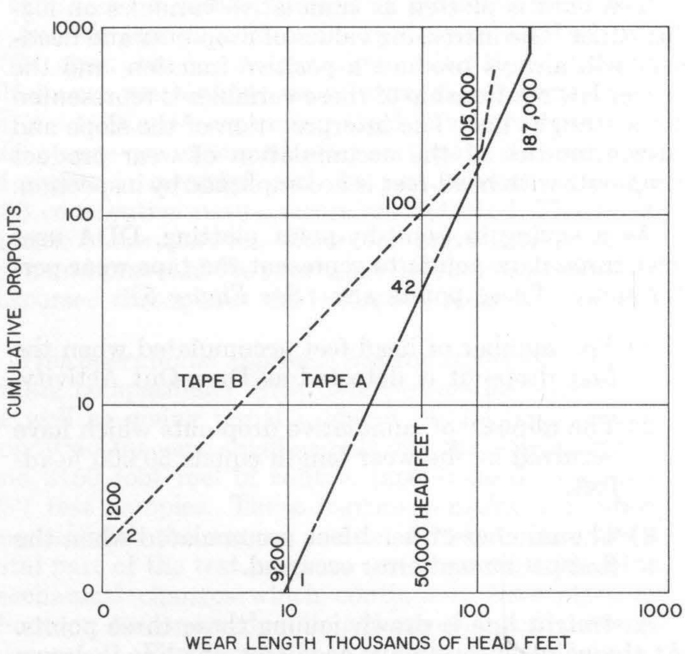


Figure 6. Cumulative drop-outs vs. wear length. Comparison presentation of two computer tapes for Durability, Drop-out Activity analysis.

The display may be interpreted as follows: As initially received and tested, tape A is superior to tape B since its first error occurred much later (9500 head-feet vs. 1200). The drop-out activity of A is superior to B since for the same wear, B has experienced greater drop-outs. In durability, A is superior to B since the first permanent error of A occurred after much greater wear than B.

These characteristics can be expressed quantitatively by making ratios of the drop-out activity at 50,000 head-feet for Drop-Out Activity and a ratio of head-feet at failure for Durability. For example, the Drop-Out Activity ratio:

$$\text{DOA Ratio} = \frac{DO_B}{DO_A}\ 50\text{KHF}$$

$$DO_A = 42 \text{ and } DO_B = 100$$

$$\text{DOA Ratio} = \frac{100}{42} \approx 2.4$$

Tape A has 2.4 times the resistance of Tape B to generate wear products.

In a similar manner, the Durability Ratio of the two tapes is:

$$\text{Durability Ratio} = \frac{\text{Wear length of Tape A}}{\text{Wear length of Tape B}}$$

Tape A failed at 187,000 head-feet
Tape B failed at 105,000 head-feet

$$\text{the Durability Ratio} = \frac{187{,}000}{105{,}000} \approx 1.78$$

Tape A resisted permanent wear damage about 1.8 times that of Tape B.

As many as three or more test results may be plotted together—one usually being a standard or reference tape. The relative merit of each tape evaluated during a brief testing interval may be compared and the resulting ratio used to compare tapes tested at other time periods. Work has been done to use this same approach with data from different transports as well as different length tests. *Figure 7* shows the drop-out activity results obtained from a tape and test performed on two different transports. The generation of wear products is a constant ratio. The significant difference of character error recognition for the FR 300C against parity error count for the 729VI accounts, in part, for the error quantity differences.

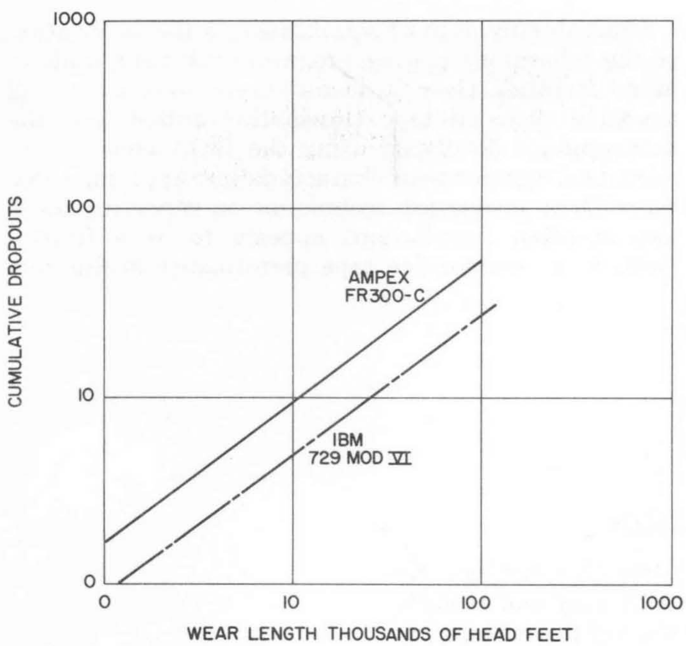


Figure 7. Drop-out Activity vs. wear length comparison using two tape transports with a single tape sample — data equally scaled for format and error differences.

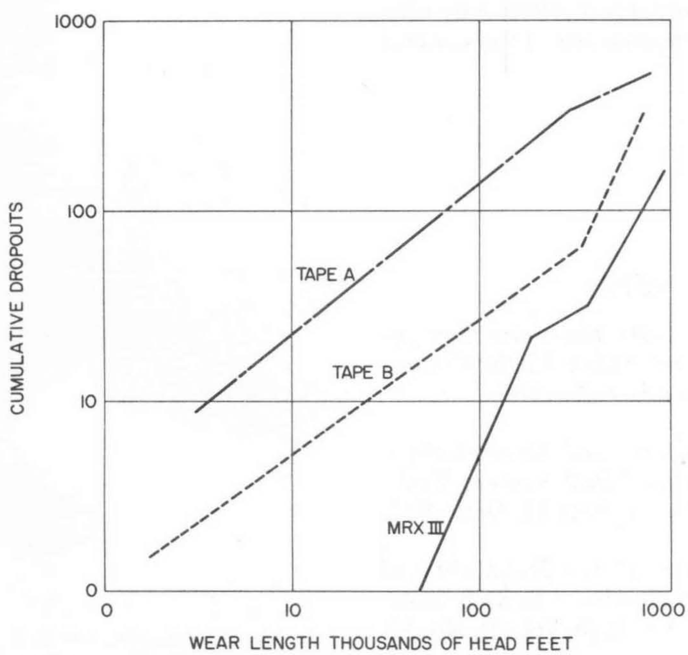


Figure 8. Drop-out Activity vs. wear length using full reel 2450 foot passes. Each curve represents a type of precision computer tape.

Figure 8 is the display of a number of tapes tested for durability by full reel wear passes instead of six-inch shuttles. In these cases, the plots represent best straight lines of the cumulative drop-outs.

The detection of a permanent error is not practical with such long tape runs. It is interesting to note that the rate of change of drop-outs indicative of terminal tape conditions occur at higher wear length than those in *Figure 6*. The abrupt changes in slope also show the self-cleaning nature of the tape at the reproduce head when long length shuttles are used for evaluation tests.

Corroborating Material for DDA

The strength of the DDA approach lies primarily in the selection of representative tests which will induce controlled tape wear. Secondarily, by use of the variable wear length term of head-feet, the resulting data follows a power law relationship which results in a linear function when viewed on log-log coordinate paper.

A significant number of papers have been published on the subject of tape drop-outs*, but are mainly concerned with the classification and detection for analog recording applications. The findings of Wallace,[2] Noble,[3] and Carson[4] combine to verify that the generation of wear products with use follows a power law relationship. Carson[5] displayed various drop-out distributions with tape wear and showed the exponential nature of drop-out activity. Noble has shown that the wear product distribution can be used as a figure of merit by observing drop-out activity as a function of wear product particle size, *Figure 9*. Lastly, Wallace has shown the power law relationship between signal loss and wear particle size. Thus, the DDA plotting method is representative of the reality of machine wear through the continued generation of wear particles with use.

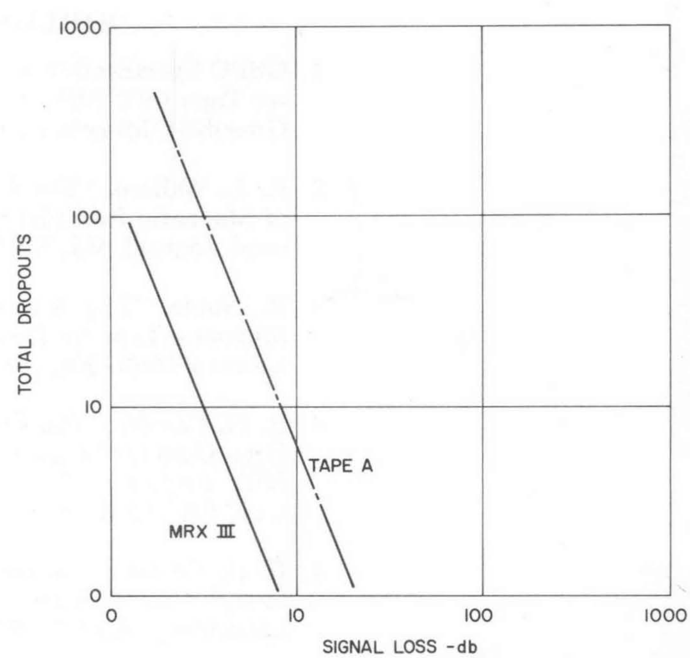


Figure 9. Total drop-outs as a function of detection level. As demonstrated by R. Noble's method of tape quality ranking. Drop-out distribution follows a power law.

**See Bibliography: 2, 3, 4, 5, and 6.*

The wear length of 50,000 head-feet was selected from studies carried out at Goddard Space Flight Center included in GSFC Specification S-533-P-10. For a shuttle length of 300 feet, there is a 90 percent probability that all precision computer tapes should not fail from permanent drop-outs when worn the equivalent of 50,000 head-feet. This wear length then provides some confidence that both Drop-Out Activity and Durability performance are separately represented on the data display.

Undoubtedly of most significance, is the verification of the laboratory testing program with field trials in users' facilities. Over 50 installations using almost all available types of tape transports verified that the tape product developed using the DDA concept, indeed, had superior wear characteristics. Applying these same DDA evaluation techniques on other machines and in other installations appears to be a fruitful method of comparative tape performance evaluation.

CONCLUSION

Application of the Durability Drop-Out Activity concept at the user level is a relatively easy and straightforward approach to the evaluation of digital tape performance. While on one hand supplying comparative ranking ability, the method is not restricted by the requirement of special equipment or a laboratory environment. Additional diagnostic information about particular tape to tape transport interactions may also become available from long term analysis of the control tape performance.

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