Proceedings of Magneto-Optical Recording International Symposium '96, J. Magn. Soc. Jpn., Vol. 20, Supplement No. S1 (1996), pp. 309-314

RELIABILITY EVALUATION OF 3M MAGNETO-OPTIC MEDIA

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Abstract - A comprehensive approach to Magneto-Optic (M-O) stability was undertaken in order to address the reliability concerns from a broad spectrum of user applications and expectations. By measuring the changes in performance characteristics, starting at manufacturing and ending with data archiving, the reliability of this form of data storage was evaluated. Stresses designed to simulate packaging, shipping, warehousing, and storage were included. Following this, the interchangability among drives and read/write temperatures was tested as well as the erase/write/read cyclability. Finally a temperature and relative humidity Eyring model was validated for previous experimentation and an enhanced model for archival life was introduced. KEYWORDS: RELIABILITY SHIPPING STORING INTERCHANGABILITY CYCLING ARCHIVAL LIFE EXPECTANCY

INTRODUCTION

In today's world of computer technology, it is difficult to define a typical user. Currently, the predominate uses for rewriteable magneto-optical (M-O) disk systems include law enforcement and financial document management, medical, military and industrial imaging, as well as scientific and defense oriented data acquisition and storage applications [1]. User expectations have grown in needs, capacity and sophistication. As dependence on these systems increases, the need for a trouble free system that operates the first time, every time becomes essential from a convenience as well as cost effective viewpoint.

Ironically, as the reliability of any system increases, the actual demonstration of realistic expectations becomes more difficult. The archival storage life of data stored on an early version of M-O disks had been estimated in terms of years [2]. Estimates on newer media now range from a few to several decades [3]. Clearly, it is unrealistic to measure these lifetimes under actual use conditions. Durable, long lasting media requires accelerated testing and sound data evaluation to produce significant results in a useful time frame. As the system and components become more reliable, the testing must become more refined if the failure mechanisms and rates can be meaningfully evaluated. The difficulty is magnified due to the high rate of new product introductions, usually offering higher data density, faster access speed and smaller size. With shorter product cycles, increased expectations and more durable material, the demand for shorter, more effective reliability measures increases.

Additionally, the concept of system reliability is one that has many widely different connotations depending upon the user, the use, the expectations, the product, the product history, etc. This is certainly true for data storage in general and Magneto-Optic media in particular.

This work addressed these broadened reliability concerns in a systematic manner. The framework for testing and evaluation commenced when the disk was first made available for use. This event was considered to be satisfactory completion of the production and quality inspection practices in place by the manufacturer. Once the media is judged ready for sale or use, reliability replaces quality as the main customer satisfaction element.

The first element of reliability addressed was the probability that a disk, having passed the appropriate production quality inspections, was in good working order upon receipt by the end user. For this test evaluation we used a simulation of an air-shipment from the manufacturer to the distributor. The stresses believed to impact reliability during shipment were limited to temperature cycling. Depending upon packaging, and placement within the cargo area, the rate of change and temperature levels reached could exceed that allowed by standard practice.

After the completion of shipment and before the receipt by the end user, the stresses likely to be encountered by the disk would be those incurred by extended storage at a distribution point. While the rate of change would be less abrupt, the possible storage conditions span the range from cold, to tropical or hot-arid conditions. Once leaving the distribution point, the next storage conditions would likely be closer to a sales point and cover a somewhat less severe shelf-time exposure.

After receipt by the end user, the next expectations are that the disks could be used interchangeably on a variety of drives, performing well in both the reading and writing characteristics of the media. The reading and writing should not only work the first time, work in many combinations but also work as many times as can reasonably be expected.

Finally, reasonable expectations would include storage of the media at moderate conditions for an extended period of time, with no loss of data.

EXPERIMENTAL

Sample Description

Specimens for all aspects of this evaluation were obtained from routine production after having passed all required testing. The specimens were obtained randomly covering an extended production period. They are believed to represent the normal product distribution in all respects.

The disks were double sided 130mm 1.3 gigabyte media composed of a polycarbonate substrate, a dielectric barrier layer, a rare earth-transition metal alloy recording layer, a spacer layer and an aluminum alloy reflector. The lacquer layer was a uv cured acrylate and the bonding agent was a thermoplastic adhesive.

Test Description

The drive testing pattern was composed of 10 areas, or bands, for read only testing and 10 for write/read testing. These bands were of equal number of tracks and together covered all of the user area of the disk.

Data was written and read by commercially available drives and an in-house software package for error measurement and tabulation. Re-allocation was off and write long was enabled. The data pattern was the drive default test pattern.

Mechanical testing utilized an in-house radial runout tester and the performance testing was measured by a commercial tester (Pulstec) operated as shown in Table 1:

Table 1: Test Parameters for Media Performance

Parameter	Setting
Threshold	1800 rpm
Bias Sens	2400 rpm
Sensitivity	2400 rpm
Wavelength	830 nm
NA	.55
Write Field	+300 Oe
Erase Field	-300 Oe
Erase Power	8 mW

The environmental test chambers were standard commercial manufacture designed for temperature and humidity testing. Standard computer controllers maintained the environments at the appropriate conditions.

For the shipment evaluation, 20 disks were baseline tested for BER and dynamic performance. These were then completely packaged. This packaging included all labeling, plastic shrink-wrapping, cardboard display case and a corrugated shipping carton.

These samples were first exposed to 7 days of rapid and abrupt changes in temperature (55 °C to -20 °C) and relative humidity (95% to <5%) followed by 7 days of rapid changes (55 °C to 25 °C) in temperature only. The temperature profile for this test is shown in Figure 1.

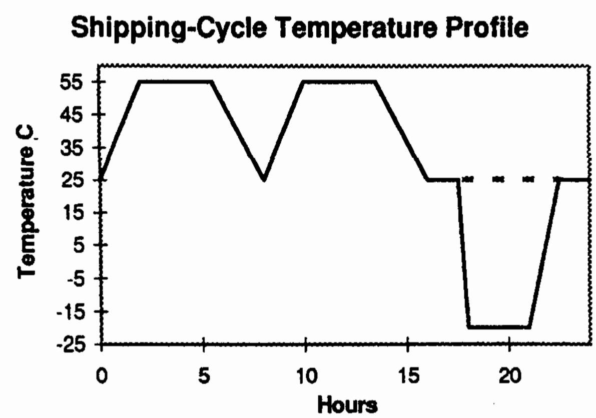

Figure 1: Shipping Cycle Temperature Profile

These disks were then subjected to simulated warehouse storage for 14 days at each of the following conditions (a), 55 °C/15% RH; (b), 31 °C/90% RH and (c), 14 days at -20 °C.

To represent various storage conditions the disks were further cycled for 5 days between -10 °C and 50 °C/21% RH. The cycling profile for this evaluation is shown in Figure 2.

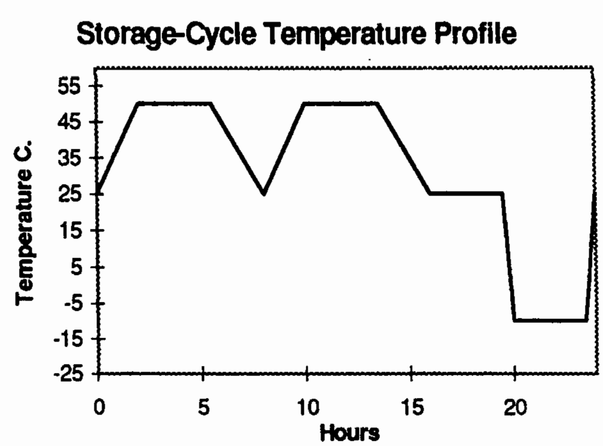

Figure 2: Storage Cycle Temperature Profile

This cycling was followed by storage for 5 days each at 50 °C/21% RH, 31°C/90% RH and -10 °C. These periods did not involve cycling of conditions.

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Having completed this interval, the disks were again tested against product specifications for new disks. Table 2 below depicts the average critical performance measurements before and after the completion of the shipping/storage stress.

Table 2: Changes due to shipping-storing disks

Parameter	Before	After
Threshold (mW)	7.10	6.65
CNR (dB)	48.1	48.2
BER xE6 Read Only	3.68	3.42
BER x E6 Write/Read	3.79	3.68
Bias Sens (%)	3.22	3.21
Stress Jitter (ns)	2.33	2.24
Axial Runout (μm)	79	67
Peak Ax. Acc. (m/s^2)	5.7	7.0
Axial Disp (μm)	66	54
Radial Tilt (mrad)	1.44	1.22
Radial Runout (μm)	21.7	21.9
Radial Acc. (m/s^2)	0.21	0.21

The disks were judged to have completed the shipping and storage evaluation essentially unchanged from manufacture.

Interchangability Testing

To determine the compatibility among drives and media, an interchangability test was conducted. For this evaluation, three different brands of commercially available drives were used. A sample of six disks were written and read using each drive combination. The writing and reading was also done at combinations of high air temperature (40 °C) and low air temperature (25 °C). These temperatures represent the ambient drive condition, the actual disk temperature inside the drive would have been somewhat higher.

Table 3 below summarizes the combinations used for the writing and reading. The brand of drive for writing is shown first, followed by the brand used for reading. Brands are designated 1, 2 and 3. Thus the combination of written on brand 1 and read on brand 2 is shown as 1/2.

By the completion of the testing there was no increase of the defect management list entry on any of the disks. The results show that all of the disks were able to be written and read by these drives at all combinations of this experimental matrix.

After completing the above testing, the disks were judged to be stable and immune from the effects of temperature and humidity cycling, both during shipping and storage as well as during normal usage under a variety of office environments.

Table 3: Combinations used for interchangability

Write Temp	Read Temp	Drive W/R	Drive W/R	Drive W/R
40 °C	40 °C	1/1	1/2	1/3
		2/1	2/2	2/3
		3/1	3/2	3/3
40 °C	25 °C	1/1	1/2	1/3
		2/1	2/2	2/3
		3/1	3/2	3/3
25 °C	40 °C	1/1	1/2	1/3
		2/1	2/2	2/3
		3/1	3/2	3/3
25 °C	25 °C	1/1	1/2	1/3
		2/1	2/2	2/3
		3/1	3/2	3/3

For testing repeat usage, it was assumed that constant erase/write/read cycling was a very severe stress. Using standard drives, and their default EWR power, one track was cycled for up to 1 million cycles. The severity of this approach stems from immediately starting one cycle after completing the previous one. No interval for relaxation was allowed. Media performance was monitored by the same Pulstec tester as described above. After completion of the cycling, the media was found to meet drive requirements.

The summary of the testing up to this point is that the M-O media construction evaluated survives a comprehensive shipping, storage, interchange and usage test.

Archival Life Testing

The final part of the reliability evaluation addresses the ability of data, once written, to survive storage for an extended period of time. In the early days of M-O development, this was considered the area of most concern. The highly reactive elements of an M-O disks needed to have protective barriers from the environment in order to survive even briefly.

There have been several studies of archival stability, many using an Arrhenius model relating degradation rate to temperature only. These models all rely on stressing disks at accelerated conditions. The critical assumption is that the degradation's rates can be extrapolated to milder stress as well as that all significant failure modes have been modeled. If this is the case, then the conclusions are valid. If, however, a change of mechanism occurs or there is non linearity along the extrapolated region, then the conclusions are unfounded.

A more thorough model for life expectancy of M-O media is the Eyring Model.

$$Tc = Ae^{(E/RT)}e^{(B)RH}$$

Where:		
	Tc =	time to failure
	A =	pre-exponential factor
	E =	activation energy
	R =	universal gas constant
	B =	second stress constant
	RH =	relative humidity

This model, while derived from the laws of thermodynamics, nonetheless shows similarities with the empirical Arrhenius model. If the effects of a second stress are eliminated, it reduces to the same equation. The assumptions are still the same and the validity must be assumed or demonstrated.

The conclusions of our previously reported experimentation showed that the media evaluated at that time had a lognormal distribution of life expectancies. This would be expected when chemical reactions are the main cause of failure. The solution of that Eyring equation produced the following parameter values.

ln(A) = -27.333 years
E = .926 eV
B=-.063

The best estimate for the life expectancy of this early media was 68 years for 95% survival at 30 °C/90% RH [4].

Model Validation:

For a validation of this model, disks from the same sample population as previously evaluated were exposed to a more realistic, but nonetheless rugged, stress of five years in a Miami, Florida environment. The disks were protected from rain and direct sunshine but otherwise experienced all of the diurnal and annual fluctuations of a subtropical outdoor environment.

Lifetime estimates from annual BER test measurements on these disks were made in the same manner as the accelerated model. The distribution of lifetimes was checked against the most common lifetime distributions and found to confirm the lognormal fit from the accelerated test. The table below shows the distributions evaluated and the corresponding goodness-of-fit.

Table 4: Goodness of fit comparisons - Miami Data

Distribution	Fit
Normal	.21
Exponential	.30
Weibull	.64
Lognormal	.79

The obvious choice of lognormal distribution is in agreement with the accelerated modeling and is part of the total validation.

The second part is the comparison of predicted values themselves. For this, the end-of-life estimates from the Miami disks were plotted on the same axis as the accelerated Eyring Model predictions for the temperatures and humidities they experienced. The results are shown graphically in Figure 3 below. The solid line represents the Eyring prediction and the dots (•) represent the results from the disks actually in Miami.

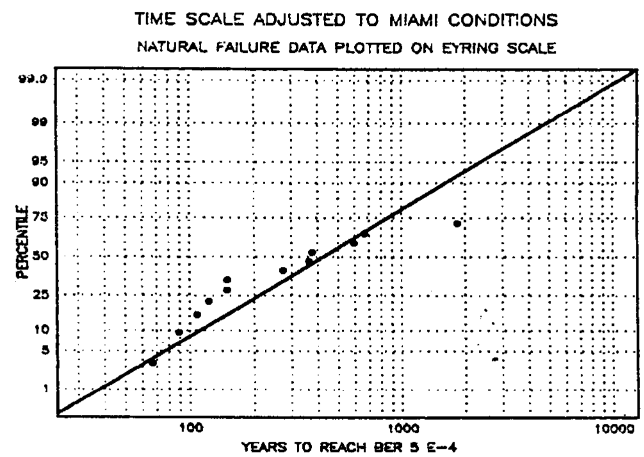

Figure 3: Miami Florida data Vs Eyring Prediction

It may be seen that a very reasonable fit was obtained, lending further validity to this model technique. Eyring modeling is becoming the basis for the emerging ANSI lifetime standards of optical media.

Archival Stability Testing:

As there had been a significant change in the composition of the media dielectric since the above evaluation, it was decided to focus only on the stability of the thin film stack for reevaluating the archival stability.

The model itself was scrutinized for ways to improve its effectiveness. The Eyring accelerated model first described above used 10 accelerated cells and a rather traditional distribution of specimen. Each cell had 16 disks apiece for a total of 160 disks. The 10 cells were twice what was required. This was not the most effective use of equipment, samples or test time. Allocating test samples over fewer cells may improve the overall accuracy [5].

Mathematically, the life estimates can be made by using as few as three temperature/humidity test cell combinations. If a check for linearity is also included, then the minimum number increases only to five.

The traditional sample distribution may be improved upon by optimization. *A priori* knowledge of average

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failure rates, acceleration factors, test duration, shape and scale factors etc. allow for estimating minimum requirements. Simply stated, the milder stress conditions will show less change per unit of time. By increasing the total time of exposure at the lower stresses, the estimate is improved. Further improvement is also obtained by increasing the number of specimen evaluated at milder conditions. A ratio of 1:2:4 is a rule of thumb for number of samples at the high, mid and low stresses [6].

On the practical side of any reliability test plan are adjustments due to sample testing time and economics, available chamber space and sample cost. Our final plan, a compromise of all considerations for this latest evaluation is shown in table 5 below: Some losses of data occurred due to a drive failure after the testing commenced. As a sufficient number of disks remained for a sound model, there was no attempt to implement correction factors or otherwise adjust for a drive replacement. All data from any disk affected by the drive failure were eliminated from all calculations.

Table 5: Compromise test plan for M-O Disks

Cell #	Temp. Deg. C	Relative Humidity	No. of Samples	Test Duration
1	80	85 %	20	2000 Hrs
2	70	85 %	24	2250 Hrs
3	70	70 %	28	3000 Hrs
4	60	85 %	38	4000 Hrs
5	60	55 %	36	4000 Hrs

The data analysis followed the same procedure as reported in our first model. By plotting the estimated time to reach a BER of 5E-4 versus median rank for each individual disk, a scale parameter was determined for each of the five accelerated cell conditions. A lognormal fit was again the best choice for distribution. Figure 4 below shows the results of such a plot for cell #1.

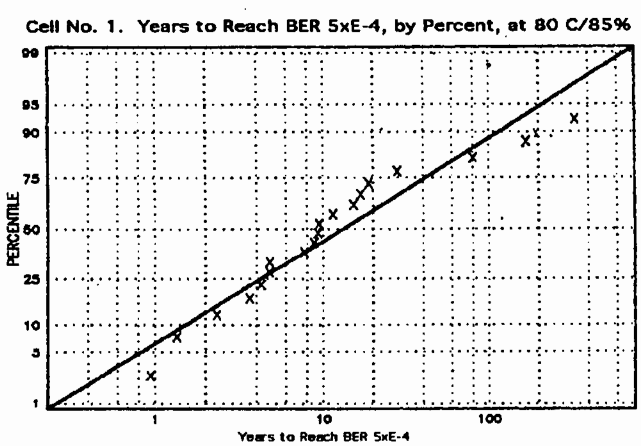

Figure 4: Lognormal Life Plot for Cell #1

Repeating this for each cell and fitting the resulting Tc, temperature and relative humidity, one can solve for the constants in the Eyring Model. The equation solution for this set of thin films were determined to be ln(A) = -48.533, ΔH = 1.542 eV and B = -.307/RH. The fitted cell parameters for this experiment are reported in Table 6 below. Acceleration factors (AF) are reported relative to 25 °C/50 %RH and 30 °C/90 %RH.

Table 6: Eyring Model Solution Values

Cell	Scale Parameter	AF - 25 °C 50% RH	AF - 30 °C 90% RH
1	6.56	12777	4193
2	28.746	2918	959
3	30.10	2786	916
4	137.5	609	200
5	150.9	556	183

When all of the individual disk life expectancies are multiplied by their respective cell acceleration factors and combined onto one common scale, the resultant lognormal distribution has a scale parameter of 83886 years and a shape parameter of 1.8772 for 25 °C/50% RH.

The fraction surviving a given time, (equal to 1 minus the fraction failing), was then used to determine how long a given percent of these M-O disks would survive. The conditions considered were both the worst case, 30 °C/90%, as well as the more likely storage conditions of 25 °C/50% A graph of the survivor function and the confidence region for the latter condition is shown in figure 5 below.

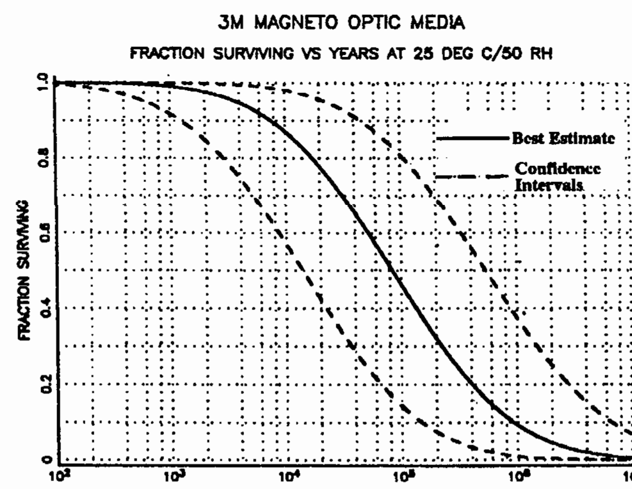

Figure 5: Survival Function for 3M Magneto-Optic Media

Focusing on the upper left portion of this graph, and expanding the scale allows one to see the survival time distribution for the 95% majority of the disks. This is shown in Figure 6 below:

The lower 95% confidence interval values are reported. in Table 7.

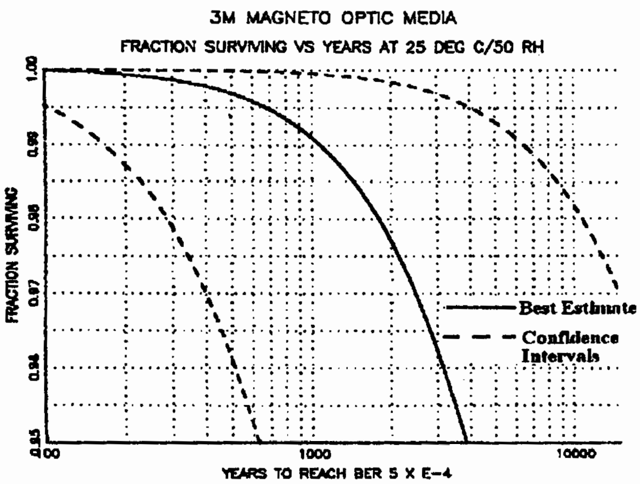

Figure 6: Expanded Scale Survival Function.

Table 7: Years of life by condition

Percent Surviving	30 Deg C 90 %RH	25 Deg. C 50 % RH
99.5	34	109
99	55	176
98	92	295
97.5	110	353
95	200	640

Therefore for the worst case storage condition, one may expect, with 95 % confidence that 99.5% of the disks will survive 34 years, 95 % will survive over 200 years. Obviously, the conditions chosen affect the value determined for end-of-life. The conditions now being standardized for calculating life expectancy, 95% confidence, 95% survival at 25 °C/50%RH [7] one can expect over 640 years archival life on 3M M-O disks.

CONCLUSION

3M Magneto-Optic disks have been subjected to a variety of stresses and testing. The objective of this broad range of evaluations was to address the concerns of an increasingly sophisticated user base. Professionals in many walks of life now depend on this media to meet and exceed their requirements for trouble free performance, time after time, use after use, year after year. The results of our evaluations confirm that the disks are robust and durable. Environmental cycling of packaged media indicates that there is no appreciable change from the time disks receive final factory inspection to the time they are received by the final user. The questions of media interchangability were addressed and the disks were again found up to the test. It was demonstrated that disks could be written in one type of drive at one set of conditions and read in another drive at the same or another condition The ability to withstand repeated usage was also challenged. After continuously erasing and writing the same track for one million cycles, the critical performance characteristics of threshold and carrier-to-noise were found to meet drive requirements.

Finally, the archivability of this media format was evaluated by applying enhanced accelerated test methodology. The Eyring model, who's validity was demonstrated with older media, was again employed for life expectancy estimations. Using the worst case storage conditions allowed, 30 °C/90% RH, the 95% confidence level for 95% survival, was shown to exceed 200 years.

Recognizing that modern archivists would certainly store records at better than the worst case situation, the life expectancy was calculated at an alternate milder condition. This condition, 95% confidence level for 95% survival at 25 °C/50% RH is also evolving as the Standardized Life Expectancy in ANSI documents on Optical Data Storage Media. The intention is to allow ready comparisons between archival media types. For the 3M Magneto-Optic disks the Standardized Life Expectancy is 640 years.

In summary, one can confidently expect that 3M Magneto-Optic disks will work reliably the first time every time over a range of drives and temperatures and that data written on these disks will remain fully readable for archival use.

REFERENCES

[1] "1994 Disk/Trend Report", Disk/Trend, Inc, 1994 p-DT12-6

[2] R. P. Freese and R. N. Gardner, "An environmentally stable. high performance, high data rate magnetooptic media" Proceedings, SPIE, 529, 1985, pp 6-11

[3] M. Tsuchihashi and M. Asakawa, "Test Procedure on Optical Disk Reliability", Mitsubishi Denki Giho, 66, 1992, pp 43-48

[4] W. P. Murray, "Archival Life Expectancy of 3M Magneto-Optic Media". J. Magn. Soc. Jpn, 17, Supplement No. S1, 1993, 309-314

[5] W. Nelson, "Accelerated Testing" John Wiley Interscience, 1990 p-36

[6] W. Q. Meeker and G. J. Hahn, "How to Plan an Accelerated Life Test" ASQC Basic References, 10, 1985

[7] ANSI IT9.21 "Life Expectancy of Compact Discs (CD-ROM) - Method for Estimating, Based on Effects of Temperature and Relative Humidity - Proposed Standard