Tape Technology

Tape technology is an important factor in the realm of digital publishing since it fulfills an absolutely essential need, namely cost-efficient data back-up and archiving. The publishing process is uncompromising in its requirements to meet deadlines, and at the same time maintain the integrity of its data. It is also a highly storage-intensive process, requiring large capacity hard drives for imaging, publishing, and multimedia files. The multi-gigabyte capacities of today's hard drives necessitates the use of tape, since there is no other storage medium with comparable data density. Tape is the only reasonable media choice for back-up and archiving since it affords the highest density storage, at the lowest cost-per-gigabyte, and provides the prospect of a complete back-up onto one or more compact, light-weight, and inexpensive cartridges.

The Rationale for Data Protection

A business of any kind requires unrestricted and reliable access to its data, whether it is in the form of publications, financial records, employee files, or other critical business information. The creation of data, either through human effort, machine-generation, or process-monitoring, has a measurable value…one that a company does not want to pay for more than once.[1] The effort, or work, that is represented by a file is only as reliable as the storage medium that holds it. Unfortunately, all forms of storage devices are susceptible to mechanical and electronic failures, power surges, read/write errors, environmental disasters, media surface damage, human error, sabotage, etc. Nothing is absolute…the only reasonable protection is a high degree of redundancy…multiple copies of data on multiple pieces of media.

The results of a major data loss can be devastating to a business. Accounts in the *Disaster Recovery Journal* show that 90% of enterprises that are subject to a worst-case disaster will go out of business within 24 months. After the World Trade Center terrorist bombing in New York City in 1993, for example, approximately half of all the businesses that did not have off-site data recovery, went out of business within 12 months.[2]

An intelligent data protection scheme is a necessary component of every enterprise, and is indispensable in a digital publishing environment. Users should implement a program themselves or contract with a service bureau to conduct the operation. Data protection is accomplished for the following purposes:

- Storage. Although hard disk storage prices have dropped, it still does not make sense to store completed premedia work, RIPped files, and finished customer work on-line. Such work should be copied to removable media, most likely tape, for off-line or near-line storage. Inexpensive off-line storage makes it possible to save multiple versions of jobs, and to save multiple copies on separate pieces of storage media.
- Archive. Data stored in an archive is distinguished by its need for long-term storage. Data in an archive generally has some intrinsic business value, such as essential financial records or important customer files. The data may also need to be maintained to satisfy legal requirements as specified by government agencies, such as the IRS. Archived data is often stored off-site[3] so that it is immune from any on-site catastrophe. Although the concept of an archive is for long-term storage, the archived data should not be kept on the same media for an extended period. Over time archived data must be

[1]FujiFilm Computer Products estimates that it can take up to $50,000 to re-create 1MB of data. "FujiFilm Guide to Protecting Your Data," FujiFilm Computer Products, Elmsford, NY, 1998, p. 2.

[2]*Disaster Recovery Journal,* PO Box 510110, St, Louis, MO 63151, 11131 E. South Towne Sq., St. Louis, MO 63123, 314 894-0276, http://www.drj.com, fax: 314 894-7474.

[3]Off-site storage assumes that media is properly handled, labeled, filed and stored in an environmentally-controlled and secure facility. Archived media must be inspected periodically and retired prior to the end of its useful life. Any obvious physical damage to the media, such as a cracked case, or prolonged exposure to excessive heat or cold is cause for replacement. In addition, tapes should be duplicated prior to releasing them for off-site storage, and the copy should remain with the originator.

copied onto fresh media. Archives are considered to be of three kinds:

Short-Term Archive. A short-term archive is maintained on active media that is used to backup a contemporaneous system.

Medium-Term Archive. A medium-term archive is maintained apart from the system, and consists of data that is moved off of the originating system.

Long-Term Archive. A long-term archive exists as a master record for legal, financial, historical, or academic reasons. State and federal requirements vary, and apply differently to various data types. Business records must typically be maintained for 7 years to permanent; contracts, leases, and agreements are usually 7 years to permanent; employee and human resource records are usually three years; payroll and benefits records are usually three to seven years.[4]

• Back-up. Data back-up is the process of making a copy of critical business files as a contingency, to be used in case the original becomes unreadable, is incorrectly altered, or is accidentally or purposely (through sabotage) deleted. Back-ups are of three kinds:

1. Full Back-up. As the name implies, a full back-up writes all data to tape, without regard to whether it has been written to tape before or not. The full back-up is the safest way of ensuring that any needed file can be recovered from the date of the last full back-up. Full back-ups are usually executed on a periodic basis, such as weekly, or monthly. Daily back-ups tend to be incremental.

2. Incremental Back-up. An incremental back-up uses the full back-up tape as its foundation, and only copies those files which have changed since the last back-up. The process is cumulative, with a new incremental data stream created during each session. Although it is faster, it is not a true archive of the data since it retains files that may have been deleted from the source disc. These files, unfortunately, would be re-copied to the source disc during a full restore.

3. Differential Back-up. Like the incremental back-up, the differential back-up is based on an initial full back-up. Unlike the incremental back-up it writes one differential file in addition to the full back-up to represent the most recent versions of all files.

4. Incidental or On-Demand Back-up. In this situation a back-up of a given job, application, or set of files is made to respond to a given need. Such back-ups are generally unscheduled and meet specific project needs.

• Disaster Recovery. The inability to access mission-critical files constitutes a business emergency, the only solution to which is the recreation of the files, or their restoration from a set of back-up media. Such files must be maintained off-site so that they cannot be affected by local property damage, such as flood or fire.

Data back-up is only half of the equation. The other half is *data restoration*. Data back-up is a defensive move, providing insurance against data loss; on the other hand, data restoration is its ultimate goal…to be able to restore any data, from a single file to an entire volume, with no data loss. It is the use of the restore function, and its successful completion, that is the payoff for the entire time-consuming data recording process.

The data recording process has as its immediate objective the accurate recording of its target data. The integrity of the data is of supreme importance since there is little hope of a successful data restore without a successful data back-up. For this reason, users are encouraged to keep tapes in rotation so that they receive balanced use, and

[4]Data retention standards as listed in Title VII; Federal Discrimination Laws; Fair Labor Standards Act; Age Discrimination in Employment Act of 1967; Americans with Disabilities Act; Title 36, Code of Federal Regulations, Sections 1228 and 1234. The IRS provides tax incentives for users to buy and maintain data retention systems. Computer users are liable for the loss of computer records and are subject to fines of up to $100,000, or a prison sentence of five years.

are never kept beyond their expected length of reliable service.

The routine scheduling of the back-up process will be dependent upon several factors, most relating to convenience, and the goal of not interfering with normal business operations. Some businesses, which are highly transaction-based, such as banking, do regular back-ups throughout the day. Others back-up at night, or at the end of a shift. In certain circumstances, non-attended, automated back-ups are possible.

Back-ups which occur when the server or work-station is not in use, and therefore consist of data which remains static, are called *Cold Back-ups*. In a digital publishing environment, most back-ups are of this type. The opposite is a *Hot Back-up,* in which the process is conducted while users and applications are actively reading and writing data. Under such circumstances the back-up will never be a complete and accurate mirror image of the data source.

Even though a back-up process is, by its nature, redundant to the data that it is backing up, a reliable back-up procedure must itself be redundant. This is because the back-up medium, most commonly tape, won't be used to restore data unless the "original" source is not available. If the back-up is not readable, there is no further recourse, except recreating the data. For this reason a formal back-up procedure follows one of several recognized media rotation schemes, such as:

Grandfather-Father-Son. The Grandfather-Father-Son is the most common media rotation schedule (FIG. 1). In this scheme there are backup sets for each day (son), each week (father), and each month (grandfather). As with any backup rotation scheme, tapes need to be periodically removed from rotation and stored for archive use.

Tower of Hanoi. The Tower of Hanoi rotation scheme (FIG. 2) is based on the puzzle invented by the French mathematician Edouard Lucas in 1883. The puzzle involves the movement of a series of various size disks stacked on one peg, to another peg. The movement of the stack requires the use of an intermediate peg, and requires that a smaller disk is always stacked on a larger one. This rotation scheme runs for 16 days with the first set of media, designated as "A", used every other day. The "B" set starts on the first non-"A" day, and repeats every fourth backup session. The "C" set starts on the first non-"A" or non-"B" day and repeats every eighth day. The "D" set starts on the first non-"A", non-"B", or non-"C" day and repeats every 16th day. Set "E", which is used on the 16th day, alternates with set "D".

Month 1				
Mon.	Tues.	Wed.	Thurs.	Fri.
				Week 1
				Week 2
				Week 3
		Wed.	Thurs.	Week 4
Mon.	Tues.	Month 1		

FIG. 1: The Grandfather-Father-Son media rotation schedule is very popular. It requires the reuse of the daily tapes, which are represented by the dark tint boxes. The most recent backups are represented by the white squares, with all other tinted squares representing previous backups.

The data protection process must be planned so that it is executed on a formal schedule, with absolute adherence to established procedures. Backup cycles must be timed to meet the needs of the enterprise, and they must be conducted faithfully, without exception. The backup software must be configured to include all specified files, and the backup operation must be carried out with precision, either through an automated process or following clearly defined operator instructions.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A		A		A		A		A		A		A		A	
	B				B				B				B		
			C								C				
							D								
															E

FIG. 2: The Tower of Hanoi Media Rotation Schedule.

Each tape, and there are likely to be many of them, must be labeled clearly and accurately. Use of the wrong tape can be catastrophic, since it will likely overwrite data for which there may be no back-up.

The data that is backed up, and the media onto which it is copied, should be thought of as two distinct things. The media can fail, leaving the data unrecoverable. The data must be maintained in redundant forms, and the media must be cycled so that it is not used beyond its expected lifespan.

Tape Media

Tape technology has undergone several developments, from helical scan tape technology, which was derived from 8mm home video, and led to 4mm digital audiotape (DAT), to the popular quarter-inch cartridge linear tape (QIC), and well beyond. There are several tape technologies available, some nearing the end of their technical lives, others beginning. The lack of standards, and the pace of rapid technological change, necessitates that users are aware of their options, and recognize when it is advantageous to switch to a new or different form of tape media.

Tape media is always enclosed inside a cartridge of some kind, which serves to protect it from the environment, and houses the various mechanisms that hold and transport the tape. The cartridge is a protective shell that enables the use of its tape contents, carries an identifying label, and stores easily in a rack, or on a shelf. In the case of AIT tape, the cartridge contains nonvolatile memory which retains important information about its tape contents.

Tape undergoes considerable stress as it is pulled from one end of its core to the other. In the process it is susceptible to stretching and other surface changes, especially in high temperature and humidity environments. Changes in the surface characteristics make reading the magnetic signals more difficult, and may result in errors, or, in the worst case, an unusable tape. Users are encouraged to "re-tension" tapes that have been sitting unused for six months or longer. *Tensioning* is the process of unwinding and rewinding the tape contents to retard structural deterioration.

QIC. QIC was invented by the 3M Company and brought to market in 1972 for the purpose of storing data from telecommunications and process monitoring applications. A QIC cartridge, which resembles an audio tape cassette, contains two reels. The tape, contained on one reel is moved to the take-up reel using a capstan, a metal rod connected to a drive motor. The capstan holds the tape against a rubber wheel which serves to move it. As the tape moves, it records data using a linear recording technique, which writes data in parallel tracks along its length. The data for each file is preceded by a header, which contains directory information. The error correction code (ECC) may be added by the drive controller or added by the recording software.

When the tape reaches its end, the direction reverses, and the read/write head advances to the next outside track, of which there may be 20 to 72. QIC has native capacities ranging from 80MB to 4GB, which can be doubled using data compression technologies.[5] The popularity of QIC technology has led to the introduction of more than 120 different standards, creating a significant compatibility problem. This problem has been addressed with the Travan specification, which uses 72 tracks, and provides some degree of backward compatibility.

[5]Data compression can be executed either in hardware or software. Hardware compression is preferable since it does not place a load on the computer processor.

Like QIC, Travan has gone through a number of generations. Its NS (network series) format was introduced in 1997. According to Imation, its manufacturer: "Products exclusively licensed by Imation with the Travan NS trademark offer read-while-write data recording and hardware data compression. Read-while-write capacity ensures data reliability by verifying the written data immediately, and rewriting any bad data blocks in a single pass, thus eliminating a second verify pass and reducing backup time in half. Hardware data compression further increases data transfer rates up to twice the native transfer rate."[6] Its TR-5 format, with 108 tracks, introduced in 1998, provides for a capacity of 10GB uncompressed and 20GB compressed.

8mm. The 8mm format originated in the video market, and it was adapted for data storage using helical scan technology. Helical scan wraps the tape around a spinning read/write cylinder, recording data tracks at an angle in respect to the tape edge. In the process, and to its disadvantage, helical scanning exerts considerable strain on the tape.

Helical Scan technology, wherein tracks are recorded at an angle, and Linear Scan technology, wherein the tape is written to tracks that are parallel to the tape edge, are the two major tape recording methods.

A refined 8mm format, called *Mammoth,* was introduced in 1996 by Exabyte. It eliminated the capstan, thus reducing tape wear.

DAT. Digital Audio Tape (DAT) is a 4mm Digital Data Storage (DDS) standard originated by Hewlett-Packard and Sony in 1998. It uses the same type of helical scan recording that is built into videotape recorders, which makes it relatively slow. The data tape is differentiated from the audio variety by stripes and recognition holes at the start of the tape, arranged in a coding standard called the Media Recognition System. The use of DAT is reserved for situations where capacity is of greater importance than speed. Two formats are standard for DAT tapes: DDS and DataDAT. They range in capacity from 2GB to 40GB (compressed).

AIT. Advanced Intelligent Tape (AIT), developed by Sony, is characterized by capacity, data integrity, and speed. The data cartridge technology, introduced in 1996, incorporates a unique integrated erasable electrical programmable read-only memory chip which stores the initial segments normally stored on tape, as well as indices of the tape content. The chip contents is read by the drive when it is mounted, providing the information necessary to locate any data file, and eliminating the need to read the individual address ID markers as the tape moves.

AIT also uses the Advanced Lossless Data Compression (ALDC) technology developed by IBM. The ALDC chip provides an average data compression ratio of 2.6:1, comparable to that achievable on tape drives used on mainframe computers.

Also unique to AIT is the media itself. Unlike conventional tape, which is composed of magnetic materials that are mixed with an adhesive to bind them to a plastic carrier, AME tape is processed through a vacuum chamber in which a vapor containing the magnetic particles is bonded without adhesives. The vapor coating is sealed with a diamond like carbon (DLC) that protects its surface from scratches.

AIT-2 doubles the capacity of AIT to 50GB and provides backward compatibility.

DLT. Digital Linear Tape (DLT) was developed by Digital Equipment Corporation in the 1980s, and was refined by Quantum Corporation in the mid-1990s (FIG. 3). The technology, which has been licensed by several OEMs, uses half-inch tape (http://www.dlttape.com/). The tape is stored in a cartridge and the drive mechanism houses the take-up reel. Data is initially recorded on a set of tracks along the length of the tape. When the end is reached, the write heads realign to record new tracks in the opposite direction. This

[6]Travan NS™ Technology White Paper, Imation Solutions for Network Storage. 1997, Imation Corp. http://www.tecmar.com/pdf/imation.pdf

continues until the tape is full. Current DTL tapes have either 128 or 208 tracks.

FIG. 3: Front view of a Quantum DLTtape 7000 drive without the external cover. (Photo courtesy of Fuji Photo Film U.S.A., Inc.)

DLT and 4mm are considered the industry standards.[7] As of early 2001, over 7 million 4mm and 1.5 million DLT drives had been sold, with the DLT segment showing the fast growth.[8]

SuperDLT, the successor of DLT, is backward compatible, an important factor considering that Quantum held approximately 80% of the tape drive market by early 1999. SuperDLT, developed by Quantum and Tandberg, uses optical and magnetic recording technologies in a process called Laser Guided Magnetic Recording (LGMR). The lasers are used to ensure precise alignment of the recording heads. The initial cartridge capacity was 110GB, with expected capacity to reach 1000GB. A significant factor in SuperDLT development is its cartridge, which uses Advanced Metal Powder (AMP) media (FIG. 4).

LTO. Linear Tape Open (LTO)(http://www.lto-technology.com) is a standard jointly developed by Hewlett-Packard, IBM, and Seagate to counter the market dominance of DLT (FIG. 5). LTO has two formats: *Accelis* and *Ultrium*. Accelis has been designed with speed as its primary feature. It can provide access to a given piece of data in ten seconds or less. Ultrium is designed for capacity, with compressed storage of 200GB or more.

ADR. Advanced Digital Recording (ADR) is a development of Philips, which was brought to market by a spin-off company, OnStream.[9] The first commercial products were released in spring, 1999 in the form of an 8mm tape with 192 tracks. The initial product was an IDE drive with a cartridge capable of 15GB of capacity (30GB compressed).

ADR is unique in that it can read and write eight tracks simultaneously. The error correction code is distributed both horizontally and vertically ensuring 100% data recovery even if up to 24 of the 192 tracks are damaged across its entire length. In addition, unlike other tape technologies which require two passes for tape surface defect mapping, ADR requires only one.

VXA. VXA, a unique tape technology introduced in late 1999 by Ecrix Corporation, uses a variable speed design to set the speed of the tape to the speed of the host (FIG. 6). This eliminates a common situation in which the drive gets ahead of a slow host, and is forced to reverse or "backhitch." The reversal of the tape is necessary since it must back-up to ensure that writing continues uninterrupted along its length. This repeated backhitching (or "shoe-shining") is not only time-consuming, but places considerable stress on the tape, reducing both its life and reliability.

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[7] "Tape Technology Seminar: FujiFilm Computer Products," Michael McCorkle, May, 2001. Presentation notes, page 2.
[8] Ibid, page 3.

[9] On May 1, 2001, OnStream Inc., was acquired by OnStream Data B.V., The Netherlands.

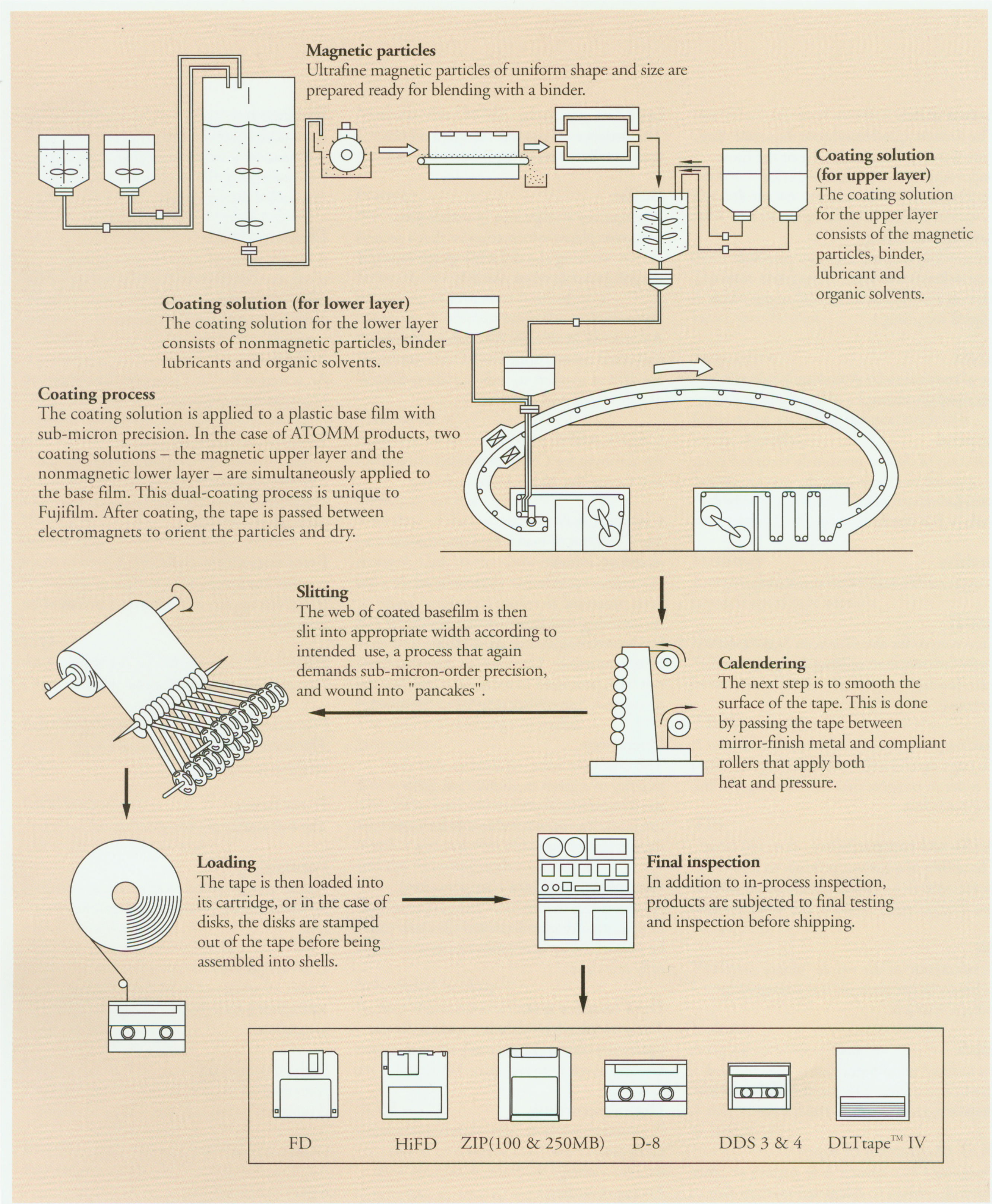

FIG. 4: The process used by Fuji Photo Film in the production of their magnetic media. (Diagram courtesy of Fuji Photo Film U.S.A., Inc., 555 Taxter Road, Elmsford, NY 10523, 800 755-3854, http://www.fujifilm.com)

FIG. 5: Front view of a Seagate Viper LTO tape drive. (Photo courtesy of Fuji Photo Film U.S.A., Inc.)

FIG. 6: The Ecrix VXA-1 FireWire tape drive incorporates several unique technologies that help to ensure fast, reliable, tape operation. (Photo courtesy of Ecrix Corporation, 5525 Central Ave., Boulder, CO 80301, 303 402-9262, 877 VXA-TAPE, http://www.ecrix.com, http://www.vxa.com, e-mail: info@ecrix.com, fax: 303 402-9266)

VXA is also unique in that it differs from all other tape technologies in the way that it writes data (FIG. 7). Rather than use long blocks of streaming data on tracks, it breaks them into small units of 64 bytes each, and encloses them with verification data (12 bytes), resulting in 76 byte data packets. This is similar to the way in which data is handled during network transmissions, or over the Internet. These small data packets, referred to as Discrete Packet Format (DPF), are more efficient to process. Combined with its technique for overscanning (see next paragraph), which ensures that data can be read from anywhere on the surface of the tape, irrespective of the tracks, VXA is an exceptionally fast and reliable storage system. The MTBF (mean time between failure) for the tape drive is 300,000 hours at a duty cycle of 12%. The VXA cartridges are rated at 20,000 media passes, and have a shelf life of 30 years.

VXA tape cartridges have been proven to be among the most reliable in the industry. Extreme tests have included boiling them for one minute in water, submersing them in hot coffee, and freezing them in ice. After they were rinsed and dried they were inserted in the VXA-1 tape drive and shown to have maintained 100% of their data.

Tape Drive Considerations

Tape is the storage media; the tape drive is the mechanism that enables reading and writing. The tape and the drive are developed and engineered as an inseparable pair.

It may be obvious that a user can't have one without the other, yet many back-up schemes that meticulously execute precise tape duplication schedules, do not employ more than one tape drive. Redundant drives can be worked into a

FIG. 7: Ecrix VXA tape cartridges support capacities of from 12GB to 33GB uncompressed. (Photo courtesy of Ecrix Corporation)

VXA is differentiated from other tape technologies through the use of its unique OverScan Operation (OSO). OSO compensates for irregular track shape or geometry by using multiple concurrent scans, ensuring absolute and correct reading. Competitive helical and linear tape technologies read tracks using techniques that are not tolerant of head misalignment, track skewing, media wear, or environmental factors. Any of these factors can result in lost data.

rotation, extending their useful lives, and working to extend the likelihood that there is at least one working tape drive in the environment at all times. In addition, when a particular type of media is retired and stored in an archive, compatible drives must be stored as well, so that the given media can be read. Countless 8", 5.25", and 3.5" floppy disks, 44MB and 88MB SyQuest Disks, and various other obsolete media formats are totally useless without a compatible drive to read them. This problem is apparent today in desktop and laptop computers which no longer have built-in floppy drives, leaving most users with legacy disks that they can no longer read.

Most tape drives provide some degree of operator feedback, indicating, for example, when the drive is reading and when it is writing (FIG. 8). These indicators are usually in the form of LEDs. In addition, the host software usually provides a display of the session progress, and possibly a real-time indication of the files that are being transacted.

Operation	LED Pattern	LED #1 ◀	LED #2 ■	LED #3 ▶	LED #4 ●
Power-On Self Test (LEDs illuminate sequentially)	See Note 1				
No Tape Loaded		Off	Off	Off	Green
SCSI Activity (LED #4 may flash with other LED operations)		Off	Off	Off	Flashing green
Tape Loading or Unloading		Off	Flashing green	Off	Light green
Tape Ready, Idle		Off	Green	Off	Light green
Reading		Off	Off	Green	Flashing green
Writing		Off	Off	Yellow	Flashing green

FIG. 8: A portion of the chart provided to Ecrix VXA-1 drive users showing some of the useful information that can be derived from the status of the LEDs on the front of drive. (Image courtesy of Ecrix Corporation.)

Simply maintaining media and a reader may not, however, ensure that the data stored on the media can be read. Even if the media and reader are properly stored, and suffer no deterioration, in time there may be no way to connect the drive to the then current computer model. Connecting a SCSI drive to a FireWire port, for example, is problematic, and becomes more so as time passes and connectivity options change. The user will have to either consider a migration to a totally different form of back-up media, or maintain a legacy computer system that is compatible with the given tape, drive, and connection format.

Another factor to consider over time is the format in which the data has been written to the media. The initial backup application software may utilize a proprietary format that only it can interpret, requiring that it is used exclusively to restore the data. If the backup software application is not available, the data can not be restored (FIG. 9). For this reason, users should try to use an application that uses an industry-standard format. This is also a factor when considering a change in back-up media technology. Backward-read compatibility should be considered.

FIG. 9: The opening screen of the Dantz Retrospect Desktop Backup software for Macintosh is indicative of its ease-of-use. (Image courtesy of Dantz Development Corporation, 4 Orinda Way, Building C, Orinda, CA 94563, 800 225-4880, 925 253-3000, http://www.dantz.com, e-mail: customer_service@dantz.com, fax : 925 253-9099)

Performance Issues

Even when everything goes right, and data is properly stored, and successfully retrieved, the inherent linear nature of tape storage is a limiting factor in its use. No matter how small a change that is made in a file, the entire file must be resaved, resulting in considerable inefficiency. For this reason users often try to segment their files, in order to work with smaller file sizes. According to Ernst Mutke, writing in *Business Solutions,* “In video editing situations, for example, producers often edit small segments of the file and leave the rest of the production as is. In this instance, there is no need to resave the entire file. In fact, resaving the entire file can cause great inefficiencies in the network by hogging the resources….File segmentation, or the ability to back up only the parts of a large file that have been changed, avoids the problem of unnecessary data backup and shaves backup and restore times from minutes down to seconds. With a proper file segmentation function, the data storage software will recognize the bytes in a file that have been changed and then update only those bytes. The rest of the file will be left unchanged."[10]

[10]Mutke, Ernst, "Segment Those Files," *Business Solutions,* May 15, 2001, p. 40.

What to Look for in a Tape Technology

Archival Rating:
- How long is the data expected to be reliably stored on the media?

Tape Life Expectancy:
- How long will the tape remain fit to read/ write data?

Storage Capacity:
- What is the capacity of the tape in both uncompressed and compressed formats?

Speed:
- What is the rate at which data is written and read (transfer rate)?

Tape Technology:
- What is the format of the tape technology?
- At what point is the technology in the course of its expected lifespan?
- How will it accommodate existing back-up and archive methods?

Performance:
- How quickly can target data be located and restored?

Reliability:
- What is the mean time between failure (MTBF) rate of the tape drive?

Cost:
- What is the media cost per GB?
- What is the cost of the drive?
- What is the cost of the software?

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