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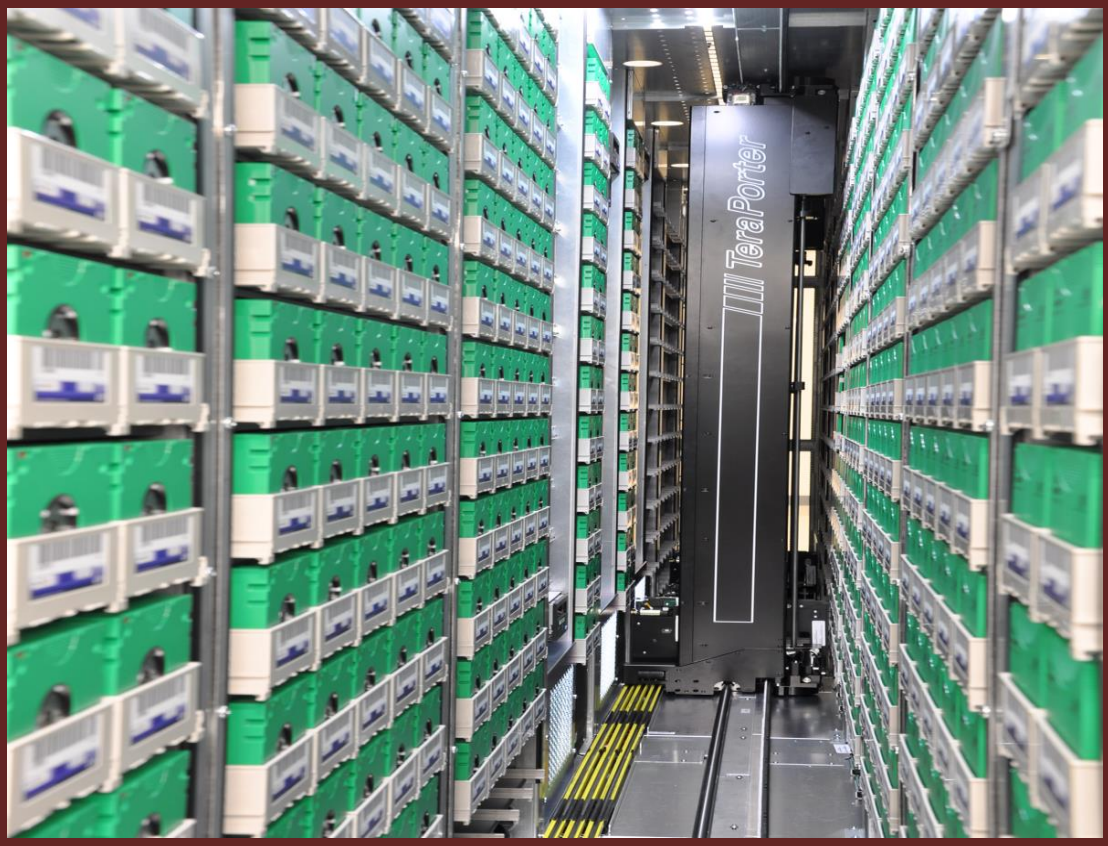


## How Contaminants Affect Tape Data Reliability at High Areal Densities


Media debris and contamination[1-7] degrades tape drive performance. As densities increase, tape drive sensitivity to debris and contaminants increase. This paper reviews the fundamental construction of (a) media, (b) sources of debris including tape related, system related and environmental, (c) how debris is generated, (d) and the effects of debris and contamination on (1) data reliability, (2) system performance reduction, (3) archivability, and (4) cross contamination of tape volumes. The paper offers recommendations for future technology needs.


***At the end of the day, one concern remains paramount: <u>Can I get my data back?</u>***

Increasing quantities of data are being stored on tape, with an expectancy of multiple decades of archive life, understanding and managing the quality of the archive library is paramount.

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# Introduction

Modern tape subsystems are robust and resilient. They represent some of the finest engineering in the world. The areal density has increased nearly 6 orders of magnitude in less than 60 years. The reliability of modern systems is markedly improved over that of only a decade ago. In general, tape offers the lowest cost, longest life storage technology available for digital data.

During the past 26 years tape systems has undergone significant improvement through automation. Some of the largest "tape farms" are now fully automated, darkened data centers. In addition, there are stand alone manually executed tape operations, therefore making tape systems the most flexible technology in the data storage industry.

Debris from fresh ("green") tape has been observed in nearly every tape environment over the past 60 years.

This paper focuses on how debris and contaminants affect drive performance, reliability and media archivability. Performance is summarized as the culmination of transfer rate, time to data, error performance, and system throughput

Furthermore, it recommends future enhancements that can markedly improve archivability and data reliability.

For purposes of this discussion, media types are limited to Metal Particle media, comprising conventional metal particles and Barium Ferrite technologies. These are the most popular formulations in use today in high capacity high performance systems.

Understanding the nature of tape debris and its impact on data reliability and drive performance, requires a basic understanding of media construction. A short introduction to media construction is presented. Due to the proprietary nature of the processes, detailed process information will not be included.

The tape industry has experienced a tremendous growth in capacity in the past 50 years.

From a few megabytes of capacity to announced products storing 5 Terabytes, amazing technological enhancements have taken place.

Much of this enhancement is the result of advanced tape media formulations.

The majority of all areal density enhancements are the result of major evolution in recording physics – head and media technology.


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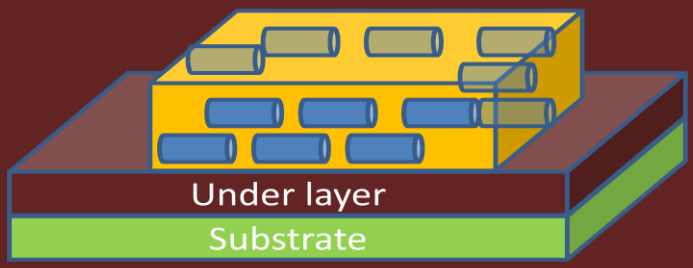
# Metal Particle Media (MP)

The mechanical and magnetic properties of the various tape formulations are markedly different. Due to the differences in manufacturing processes, materials, and mechanical properties, the mechanisms responsible for generation of debris are different for various processes and manufacturers.

Pictorial of Oriented MP Magnetic Layer




Conventional Metal Particulate media is manufactured using a process that applies a very thin layer of material on a flexible polymer based substrate. Particles are typically oriented physically and magnetically along the length of the tape. With some of the newer particle technologies, orientation can be achieved vertically – that is, perpendicular to the face of tape.

Particle types and orientation can change the debris generation profiles due to chemistry differences between binder systems, magnetic surface roughness differences, and coating thicknesses required for optimal recording.

Metal particles vary in geometry – the conventional MP particles are acicular in shape – similar to cigars. The new Fuji Barium Ferrite (BaFe) particles are platelets – similar to a hexagonal shaped coin.

- MP particles are primarily Iron based. Many are Iron-Cobalt alloys.
- ME grains are nearly pure Cobalt.
- BaFe is a platelet consisting of Barium and Iron (ferrite).

There are two major suppliers of Metal Particles in the industry – Dowa and Toda. The source for BaFe particles has not been disclosed.

The majority of the thickness of tape is the substrate. The sum of all the coatings are less than 25% of the total thickness.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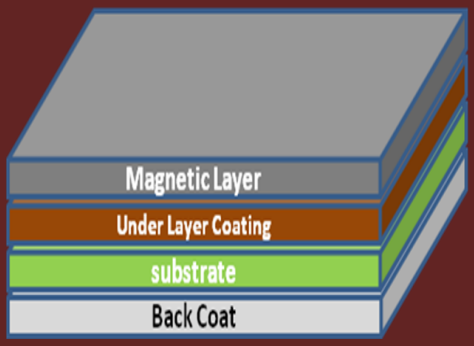
# Tape Physical Construction[14,15]

MP tape is comprised of a multitude of materials. The pictorials are provided for purposes of discussion - the pictorials are not drawn to scale. Tape related debris is directly tied to the construction of magnetic tape and associated materials.

Pictorial of Conventional Metal Particulate Media Construction




The substrate is the thickest of the media layers. It tends to dominate the majority of the mechanical properties of tape. Future generations will pursue thinner total tape thicknesses. As such, in future generations the substrate my not dominate total thickness in the future.

The surface roughness and its mechanical properties contribute to the mechanisms associated with tape related debris generation. One side of the substrate is often rougher than the other. The adhesion of the coating layers to the substrate plays a crucial role in media durability.

The tape substrate[11] is comprised of one of three polymer based substrate choices – PEN (Polyethylene naphthalate), PET (Polyethylene terephthalate), and PA (Poly aramid), all of which are in use today.

PET is the industry workhorse. It has been in use for decades, and tends to be the least expensive. PEN has been in use for more than 15 years, with a moderate price increase over PET. (PA) is an advanced substrate exhibiting superior mechanical characteristics along with the highest cost.

**Dimensional Stability (TDS)**

To guarantee that data can be read over all environmental conditions, maintaining control over tape dimensional stability is critical.

TDS is a measure of differential expansion and contraction between the physical location of active elements on the read/write head and the written tracks on tape.

Differential expansion and contraction are a function of tape tension, tape thickness, temperature, humidity, and media properties.

**Substrates**

Today, there are two major suppliers of substrates used in data storage – Dupont Teijin Films and Toray.

Teijin provides PET and PEN films, Toray provides PET and Poly-Aramid films.

Both companies continue to research advanced materials supporting the tape industry for the future.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Substrate choice is driven by many factors. Among those factors, dimensional stability requirements, drive tension, system operating temperature and humidity, total tape thickness, areal density and durability are critical components.

The thermal coefficient of expansion (CTE) (how much the substrate dimensionally changes per degree Celsius) and the hygroscopic coefficient of expansion (CHE) (how much the substrate changes in dimension per percent of relative humidity - %RH) are key design parameters for any advanced storage system. Dimensional change can contribute to tape debris generation by constantly creating motion between layers of the coating stack as well as layer to layer in the tape pack. This motion can displace already damaged and or loose particles over time.

Creep (how much the media changes dimension in the tape pack resulting in reduced tension when stored for long periods of time) is also affected by substrate choice. Creep and its associated motion tends to generate debris.

As densities increase, the cost of substrates increase as well – higher stability, lower sensitivity to temperature and humidity, smoother surfaces and thinner structures all increase cost of substrates. Much of the total media cost is associated with substrates.

One side of the tape substrate receives a coating that is optimized for guiding and stacking tape inside the cartridge. This layer is referred to as the back side of tape. This layer is typically rougher than the magnetic coating layer to improve tape winding properties at high speed. As densities increase, the roughness of this layer must be reduced. Imprinting of tape back side surface roughness in the magnetic side in a wound tape pack results in small dropouts.

The other side of the substrate typically receives 2 coating layers.[1] The first layer, the "under-layer," is next to the substrate. It is used to (a) control roughness of the substrate, (b) provide a reservoir for lubricants and (c) minimize surface irregularities in the magnetic coating.

**Dimensional Stability**

Tape dimensional stability defines how the physical tape responds to changes over time, operating/storage temperature and humidity, and stress such as tension, tape pack pressures, etc.

In many aspects, TDS (Tape Dimensional Stability) limits track density on tape.

**Creep**

When a length of tape is placed under tension for long periods of time, the tape changes length. This change is permanent – the tape does not recover once the tension is removed. This effect is called creep.

**Tape roughness**

The surface of tape is like extremely fine sand paper. The magnetic side is typically smoother than the backside.

[1] Process originally developed and patented by FujiFilm Corporation


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The second layer, the “Magnetic Layer” applied on top of the “under-layer,” is the actual magnetic coating comprised of a very thin layer containing magnetic particles, binders, head cleaning agents (HCA), solvents, etc. Specific process details are proprietary to individual manufacturers.

Magnetic particles in the top (magnetic) layer are typically less than about 50% of the total volume. The remainder of the volume contains the binder, HCA, lubricants, etc

Once the substrates are fully coated, the multi-layer sandwich is slit into widths specific to a given tape format requirement, the most prevalent being approximately ½ inch. The slitting process generates a tremendous amount of debris. The majority of this debris is subsequently removed later in the manufacturing process. Some debris however may remain on the edges and surface of tape.


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# Sources of Contamination

Tape drive error rates, re-writes, and reductions in system throughput (transfer rate) are affected by debris.

Four primary sources of contaminants can affect proper system operations. Specifically, (1) media contaminants, (2) airborne related contaminants, (3) cartridge related contaminants, and (4) drive related contaminants. Other than airborne and out-gassing sources, the remainder of the sources are related to physical motion of the tape media and cartridge.

- Media related contaminants can come from several sources, (a) tape slitting process, (b) loose debris after coating and processing, (c) HCA particles from tape being removed from the tape coating, (d) motion of the tape front side relative to the back side during winding and storage, (e) tension and tension variation resulting in loose particles becoming free to move about, (f) contact of the tape edge with tape guides, (g) contact of the tape edge with the flanges on the cartridge reel and the take up reel in the drive, etc.

- Airborne contaminants include dust, human skin, food particles, water based contaminants (chlorine, sodium, etc), green house gases, etc

- Cartridge related contaminants may include (a) out-gassing from plastic components used in the cartridge, (b) abrasive wear of the plastic reel inside the cartridge, (c) debris from the actuation of the hub lock and access door, (d) wear of the cartridge shell being inserted, extracted from the drive or library setting, etc.

- Drive related contaminants may include wear components from (a) rollers and guides, (b) head materials, (c) abrasive wear of the take up reel and (d) pretty much anything that comes into contact with the tape media itself while in motion, or relative motion.

**Out-Gassing**

Many chemically derived substances such as polymers, epoxies, carpets, etc. can over time release gaseous by-products from curing processes. This release is referred to as out-gassing.

One of the largest sources of contamination is the human body. These sources consist of shedding skin, dandruff, loose hair, food particles, and airborne liquid contaminants, etc.

Another source of debris are cleaning systems such as vacuum cleaners. Unless an absolute filter is used in-situ, they tend to exhaust small, microscopic particles as they clean, creating opportunities for debris to be picked up in HVAC systems and subsequently caught and wound in tape packs.


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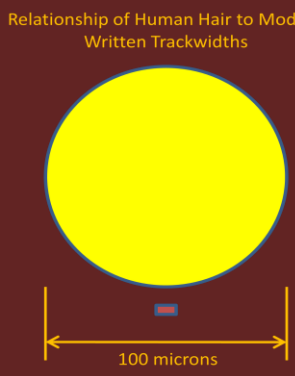
# Airborne Contaminants[13]

Nearly all installations of computer equipment involve environments utilizing air conditioning, humidification, and personnel. Airborne contaminants in sufficient quantity can create issues for reliable tape operations. Example of typical airborne contaminant sizes[12] are; (a) Pollen – 10-1000 microns (b) diameter of human hair – 100 microns (c) Cement dust – 3- 100 microns, (d) smoke (fire byproducts) - <50 microns (e) dust - <40 microns, and (f) Tobacco smoke - <4 microns.




The air handling systems transport small particles of dust, hair, human skin, etc throughout the data center. All electronic devices require some form of cooling. The cooling systems tend to collect and focus this debris in the tape drive. This debris is easily attracted to tape surfaces due to electro-static attraction, thereby allowing it to be wound into the tape pack.

Chlorine is detrimental to both tape coatings and to head materials. Free chlorine can have very detrimental effects on drive performance, eroding heads, damaging media coatings, etc.

Humidification systems may utilize ordinary tap water, leaving minerals and other elements present in the water including chlorine. Airborne humidified air can transport chlorine and other contaminants into the tape drive environment.

Salt is comprised of sodium and chlorine (NaCl). The human body is an excellent source of salt. Additionally, computer rooms located along coastlines or at sea may experience salt water contamination.

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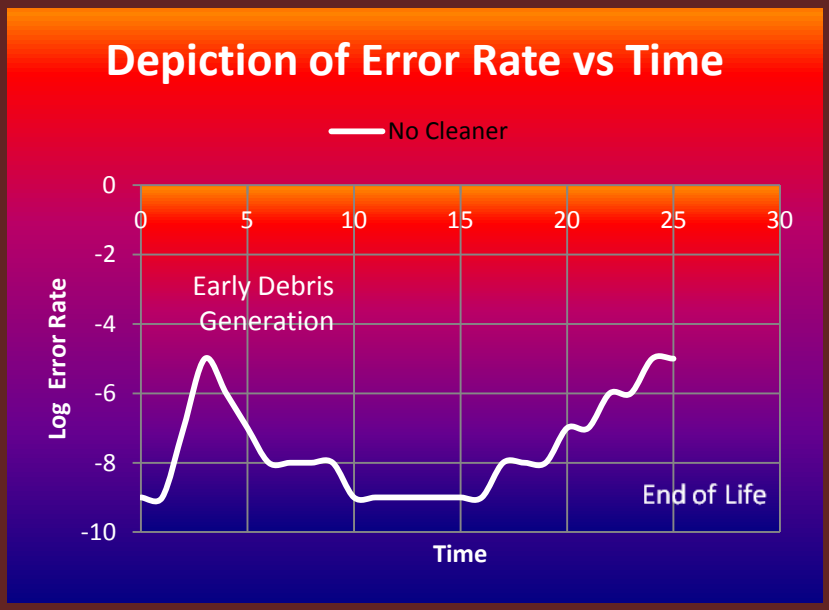
# Media and Cartridge Contaminants[3, 4, 14, 15]

Media debris is observed prevalently on initial usage of a virgin (fresh, sometimes referred to as "green") tape volume. Over the first few passes, debris is accumulated, distributed, and affects error performance and system throughput. This situation is depicted as increasing error rates early on in the chart below




Some of the debris sources are discussed below.

The slitting process involves slicing the coated media into strips about ½ inch wide and thousands of feet long. The slitting operation can leave debris along the slit edge. PEN tends to have a greater propensity of cracking and crazing along the slit edge than other substrate types. Normally, through the manufacturing process, the majority of loose edge debris is removed. When media is used in a tape drive, particles that are damaged may become dislodged and be trapped in the tape pack, subsequently impacting drive performance.

The coating processes can generate loose coating debris, most of which is removed at time of manufacture. Some debris is dislodged only after usage in the tape drive, typically after several passes BOT/EOT and back again.

Referring to the plot above, the typical drive error rate characteristic of tape shows good performance on the first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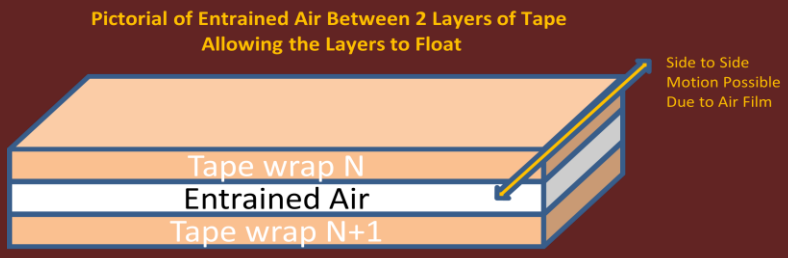
full file pass, some degradation over the next 5-20 passes, followed by improvement over the next 50-200 passes. At end of life, the error rates degrade once again. Once the error rates degrade to the point that the ECC cannot correct the degraded data, heroics must be undertaken to recover data, such as advanced error recovery strategies, tape transport swaps, etc.

Head cleaning agents (HCA) are added to the coating at time of manufacture. These particles are contained in the magnetic coating layer. Over time, they can become dislodged and subsequently become trapped in the tape pack. HCA's are typically large compared to the required head-media separation distance. Hence, their inclusion in the tape pack can cause dropouts in data.




Relative motion exists between the front side of tape and the back side of tape as tape is wound into and out of the cartridge. The relative motion of one with respect to the other generates debris.

As tape is shuttled from BOT (beginning of tape) to EOT (end of tape), media is wound into/from a tape pack. This motion provides a mechanism for the front side (magnetic side) of the tape to move relative to the back side of the incoming layer of the tape pack. Until the time that these two layers "couple" – (where the two layers have squeezed out enough air for the two surfaces to come into physical contact with one another) the tape "floats." This allows unwanted movement of tape. Due to air entrainment in the tape pack, movement orthogonal to the tape edge can occur, until the edge contacts a tape flange on a take up or supply reel.

Similarly, as tension is applied down the length of tape, the tape physically changes dimension. The tape becomes longer, it shrinks in tape width, and it becomes thinner. This effect is easily observed in a rubber band – the more it is stretched, the more it changes in dimension. These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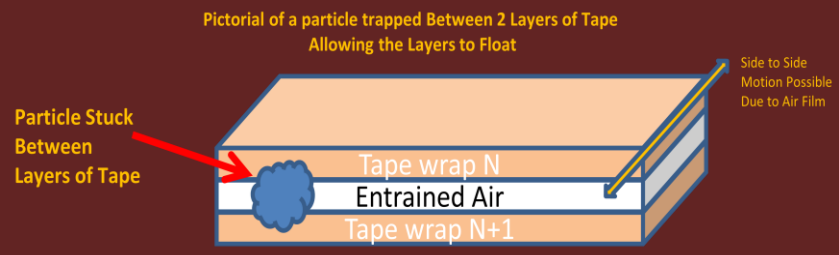
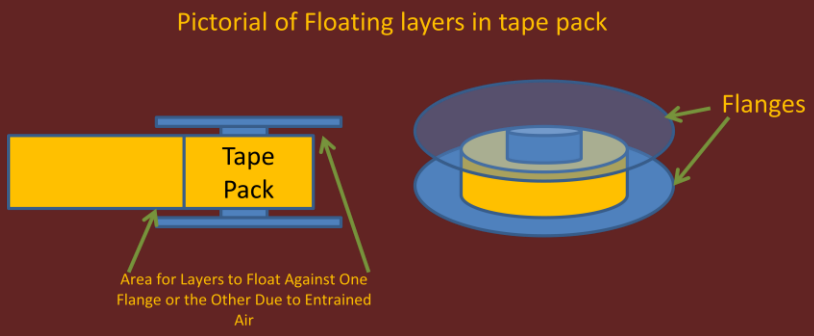
dimensional changes can over time generate small amounts of debris that can get trapped in the tape pack.

As tape is allowed to sit on the shelf for long periods of time, the tension in the tape pack is relaxed due to creep previously discussed. This relaxation subsequently can generate some debris, especially in outer layers of the tape pack.




Any debris that is trapped in the tape pack over time will imprint its physical dimensions into the surfaces of the tape[13]. This is most observable deep in the tape pack where the hoop stresses[11] are the greatest (closest to EOT).




The tape edges are a rich source of debris – rich in substrate particles as well as coating particles from the slitting operations.

The tape edges come into contact with tape guide flanges (if used) and potentially with the flanges of the take up and supply reels in the cartridge and drive.

As tape is wound into a supply/take up reel, air is entrained between layers of the tape. It can take tens of wraps for the air to be squeezed out of the layers. This air provides for a low friction platform that allows the tape to freely move from flange to flange. When the tape direction changes,

**Hoop Stress**

Tapes may be 1000 feet in length, or more. In a cartridge, thousands of layers of tape are wound one on top of the other. Starting at the innermost radius and working outward, each subsequent layer applies pressure on the layers below. This results in very high pressures at the inside radius of the tape pack with exponentially lowering pressures towards the outside diameter. The stress associated with these pressures and gradients is referred to as hoop stress.

**Tape roughness**

The surface of tape is like extremely fine sand paper. The magnetic side is typically smoother than the backside.

Once the air film is squeezed out between the two sheets of "sandpaper," and the surface asperities couple, motion of the two tape layers in question typically ceases, and the two layers settle together.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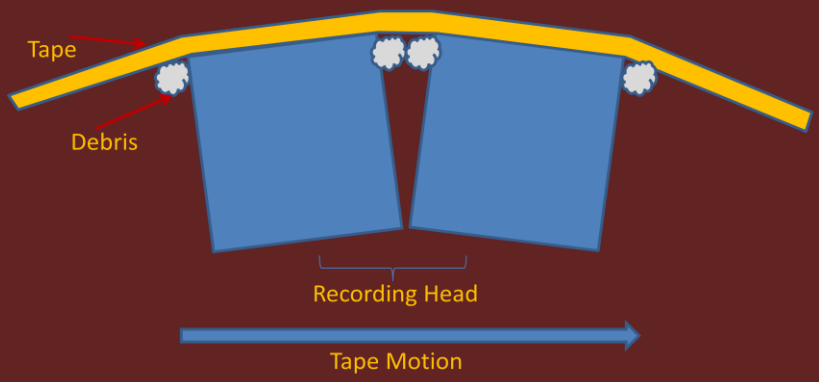
tape edges contacting with reel flanges will generate debris from tape and debris from the reel flange.

## Drive Related Contaminants

There are many moving mechanisms inside a tape drive. Anytime there is relative motion taking place between two components, there is a potential for debris to be generated. In this particular case, motion of tape relative to the head assembly is the point of discussion.

Tape heads utilized in modern tape drives vary radically from product to product and from manufacturer to manufacturer in details and materials.

Pictorial of Debris Being Collected by Recording Head and Carried Along




As tape moves across the leading edges of the head contour, debris collects along the edge. If sufficient debris is collected, it can change the flight dynamics of the head contour. This can affect reading and writing performance. If the effect is observed on the "write side," the overall quality of the recording can be degraded.

As described above, using the head as a "scraper" can be a source of debris when the direction of operation is reversed, spreading debris all over the tape surface.

In normal operations, tape drives are either throttled to attempt to match the transfer rate of the drive to the host, or undergo a significant number of start – stop – reposition operations. During reposition operations, the head acts like a small snow plow – moving debris back and forth, depositing it in piles along the tape surface. Then, when the tape is

Office environments can provide additional sources of debris that can be caught in tape packs. Examples are:

- Toner particles from laser printers.
- Paper dust from handling large quantities of paper, or from large impact printing facilities.
- Exhaust from delivery trucks – typically carbon based molecules.
- Airborne salt byproducts from people carrying it in on their shoes during the winter.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either rewound, or sent to EOT, the debris is scattered about on the tape surface.

## Performance Impact Summary

Performance is summarized as the culmination of transfer rate, time to data, error performance, and system throughput.

The debris under discussion is microscopic. If it can be seen with the unaided eye, it is far in excess of what a normal tape drive can deal with reliably.

As previously stated, the diameter of the human hair is about 0.004", which is about 100 microns. The track width (written) of modern devices is at or below 10 microns – one tenth the thickness of the human hair. The read track width is in many cases less than 50% of the written track width.

Not only is the reproduce process compromised by debris, but the recording process[16] can be impacted. By impacting the recording process, the built in system margins are reduced, thereby potentially placing the future archivability of data at risk. This is dependent upon how much separation has taken place between the head and media.

Should the error performance degrade sufficiently during reading, the tape drive will enter retries and re-read operations. If encountered during writing data, it attempts to re-write the data further down tape. Any of this activity reduces the device throughput. Both time to data and transfer rate is affected.

High areal density tape systems achieve their capacities through a combination of linear density and track density enhancements. Some companies prefer to push linear density. Others prefer to increase track density. Each has its strengths and weaknesses.

***In the next section we will explore how linear and track density is impacted.***

**Reproduce Process**

The process of reading a set of data from a recorded tape volume is referred to as the reproduce process.

All modern tape devices are designed to deal with some amount of debris. Only when the amount of debris and contamination is excessive will the devices have difficulty dealing with the debris.

**Anecdote**

Remember the story about the patient that went to see their doctor?

The patient complained "Doctor, it hurts when I do this" while raising his arm.

The Doctor replied,"Well, don't do that!"

Debris management is similar – minimizing the generation, buildup and transport of debris is critical moving forward. What the industry has tolerated for so many years can no longer be tolerated.

It is time for fundamental change in how tape is managed, stored, and prepared for use.


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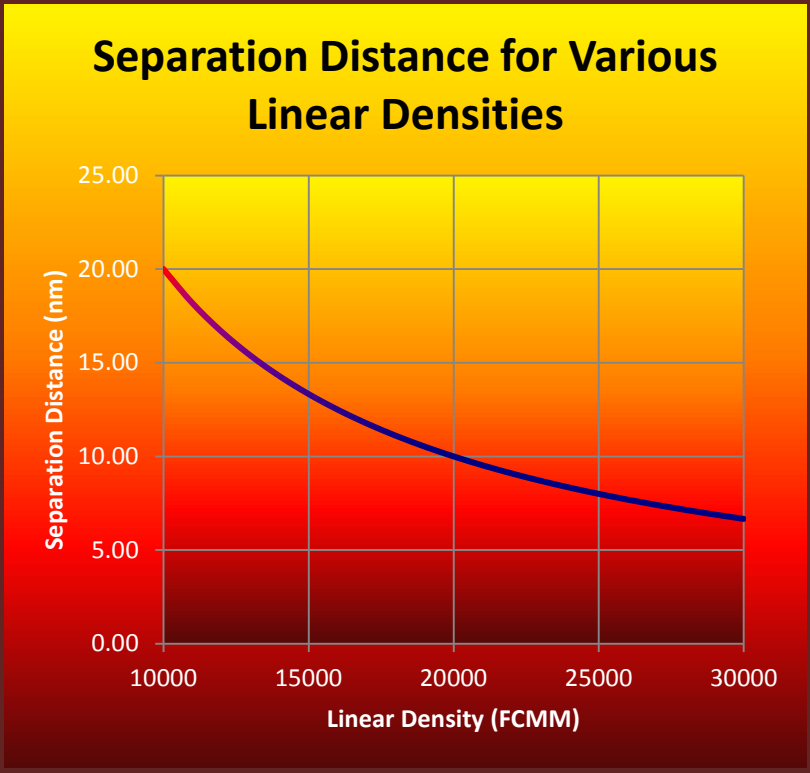
# Linear Density Effects

Modern tape systems have experienced a significant increase in density over time[17]. From 128 BPI (Bits per Inch) in 1951, GCR at 6250 BPI in early 1970's, 3480 technology at 19 KBPI (1000's bits per inch) in the mid 80's to the most recent announcements of 4 and 5TB (terabytes) capacities (native). Linear densities today are approaching 500 KFCI, perhaps more. This places significant pressure on the head – tape interface to achieve required performance.

As densities increase, debris plays a more significant role in degrading data quality. Managing debris is paramount to success at high density.




As can be seen from the plot, as the linear density increases, the effective head – media separation must be reduced[18,19]. Looking at the range of modern devices (10-20KFCMM) separation is quite a challenge. Maintaining a 10nm separation (1/100$^{th}$ of a micron) requires a high integrity head-media interface.

This plot represents a 6 dB loss in amplitude, 3 dB loss in Signal to Noise ratio for the densities in question. A 6 dB loss

**Linear Density**

10,000 FCMM (flux changes per millimeter) is equivalent to about 250 KFCI (1000's flux changes per inch); Subsequently, 20,000 FCMM is 500 KFCI.

**Separation Distance**

The diameter of a water molecule is about 0.3nm. The required separation distance to support 500 KFCI (20KFCMM) is 30 water molecules!

**Track Width Comparison**

When compared to the written track-widths, the track-widths are huge! Nearly 500 times the separation distance required to support 500 KFCI.

**Signal to Noise Ratio (SNR)**

SNR varies directly with the square root of the read track-width (typically about 50% of the written track-width).

SNR varies inversely with the square of the linear density. Increases in linear density come at a very high SNR price.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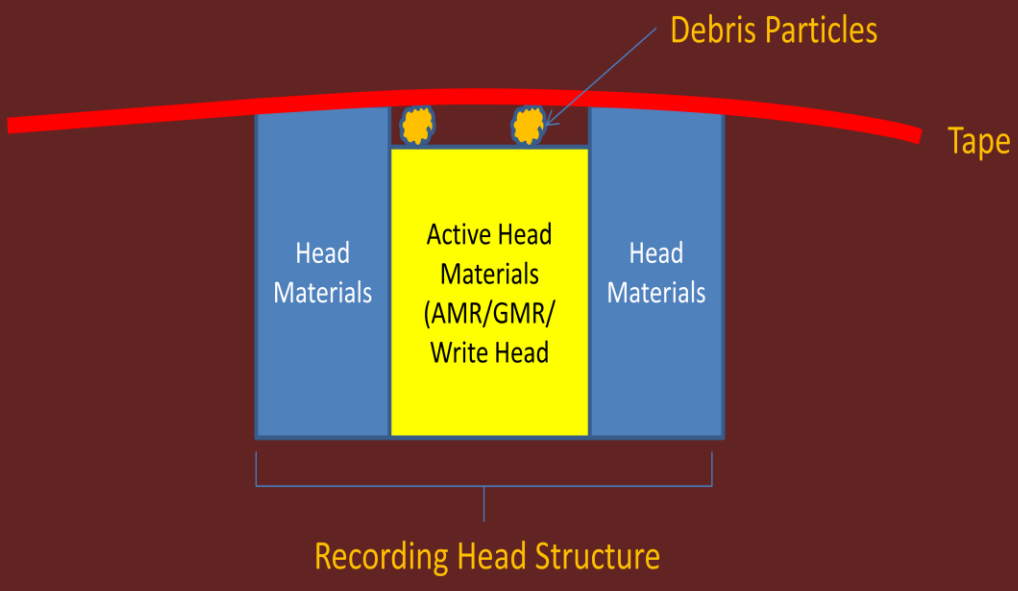
implies that we lose half of the output from media at these separation estimates. At increased separation estimates, the losses become staggering. Additionally, this implies that the control over debris becomes even more important as the linear density is increased, since debris/staining results in increased separation for a period of time.

Another form of material buildup that affects performance of the head assembly is staining.

This is an electro-chemical reaction that takes place at the head tape interface that is still being investigated. Methods to control it, eliminate it, or even model it are not well understood today. It primarily affects materials in the head assembly. A slight amount of staining is good; a large amount is very detrimental.

Some staining tends to provide protection for active head elements. Too much stain, and the separation distance becomes detrimental. Balancing stain and media abrasivity is a tremendous challenge.

Pictorial of 3 Body Wear, mobile debris, etc





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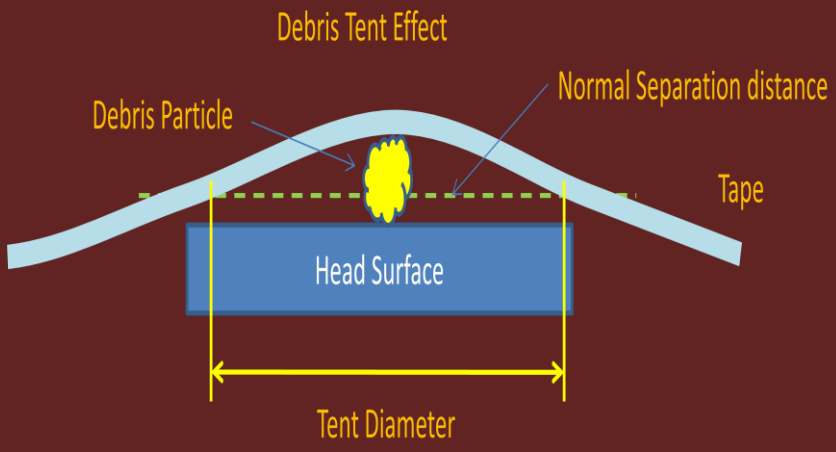
# Track Density Effects

Tape has moved from 7 tracks on ½ inch tape to more than 2500. The written track widths have been reduced to microscopic widths, less than 1/10th the diameter of the human hair.




Debris results in the tape lifting off the head assembly active sensor regions. Given the tape tension, tape properties, head contour, etc, a debris particle 1 unit high, can have an effect 50 times (or more)[6] that distance in all directions, across track, and down track. This is commonly referred to as tenting effect.

The good news is that the distance between adjacent channels is quite large – many times the written track width. Therefore, multi channel errors are rare.

In a modern tape system, data is recorded in a serpentine manner; multiple passes from BOT to EOT and from EOT to BOT are required to fill a tape. Each pass records information on a different "wrap" and physical location on tape.

While the drives utilize multiple channels (16 or 32 as an example), these tracks are not adjacent to one another physically – they are separated a fairly large distance, typically many times the written track width.

As a consequence of this channel separation, differential expansion and contraction takes place between the head the media due to temperature, humidity, tension, and aging.

To minimize the effects of dimensional change, tapes are divided into multiple bands, typically either 2 or 4. Each band is then broken down into various "Wraps."

To guarantee that data can be read over all environmental conditions it is critical to maintain control over tape dimensional stability.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## Archive Considerations[1, 2, 3]

Debris can be trapped in a tape pack during normal operation. This debris can result in localized regions of the coating being imprinted into the surface of the layers of tape (top and bottom). If the imprint is too deep, the data underneath the imprint will not be recoverable, and must be re-constituted utilizing the built in Error Correction Code (ECC). As long as there is not too much contamination, data should be recovered without issue. If the debris/contamination is excessive, the reliability of the tape volume could be at risk. The more debris, the more the imprinting, the bigger the risk.

## Mobile Debris Impact

There are two type of debris –that which moves freely (mobile debris) and that which is stationary (sticky debris).

Debris/contamination can and does move about. The head can and does act as a snow plow. All "snow plows" tend to leave "snow" behind. Changes in direction tend to spread debris behind the head that was previously in front of the head. This can effectively contaminate a previously verified data set, and as a result could place it's recovery at risk. Furthermore, the snow plow effect tends to pile up debris at EOT and BOT – where it is easily carried to other tape wraps and channels.

Damage to both tapes and heads can occur from debris. Hard particles can scratch the tape surface if they get stuck to stationary components like heads. Additionally, mobile hard particles can damage the very sensitive AMR/GMR read heads rendering them marginal/failing.

Debris also acts like a lapping compound. Debris accelerates wear of stationary tape path elements through what is known as third body wear. Debris can abrade softer structures like the materials used in the construction of AMR/GMR heads and other materials at the head-media interface of the head assembly.

**AMR/GMR Heads**

Modern read head technology used in tape drives involve technology known as AMR (Anisotropic Magneto-Resistive) and GMR (Giant Magneto-Resistive) sensors. They provide for enhanced read signal amplitudes from high density recordings.

IBM 3480 was the first Tape product (released 1984) that utilized AMR sensors.


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## Sticky Debris[3]

In certain cases, heavily used tape can become an issue. Loose debris can get mixed with excess lubrication by-products generating a relatively sticky substance. This sticky substance can stick to tape guides, rollers, tape, heads, etc. What makes this kind of debris most damaging is it has an affinity for anything that is hot – like the active elements of an AMR/GMR read head, resulting in a "baked on" substance.

Once debris adherence takes place, it increases separation distance between the active elements and the tape. Furthermore, it acts as a local point of stiction – causing the tape to stick to the adherent debris when tape is stopped.

Once tape motion resumes, the adherent debris can actually pull out small microscopic segments of the tape coating it was in contact with, further growing the size of the spot, and damaging the tape surface from which the material originated.

The best method to deal with this debris source is to not over use a given tape volume. Retire it as per the manufacturers recommendations.

## Library Cross- Contamination Effects

While mobile debris can be transported from tape to tape due to a contaminated drive, it is rare that enough debris is migrated to cause any issues.

However, the sticky, adherent type of debris can move from tape to tape contaminating multiple tape volumes. This is usually referred to as an inhibitor tape. In large library systems it is nearly impossible to identify a specific cartridge that is responsible for contamination. The usual fix is to replace an entire library of media, and all drives.


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# Mitigating Effects of Debris and Contamination

All told, modern systems are robust. However, as densities increase, more and more attention needs to be paid to debris and contamination. The real question is simple: Are the mechanisms built into the drives sufficient to guarantee system robustness and longevity of recordings?

At the media level, additives and process enhancements are added to remove small amounts of adherent debris and staining. This is controlled through media abrasivity. It acts like fine sandpaper – continuously cleaning the head surface. As temperature and humidity changes, so does the ability of the tape to clean debris and contamination off the head and usage tends to degrade the cleaning effect of tape due to reduced abrasivity.

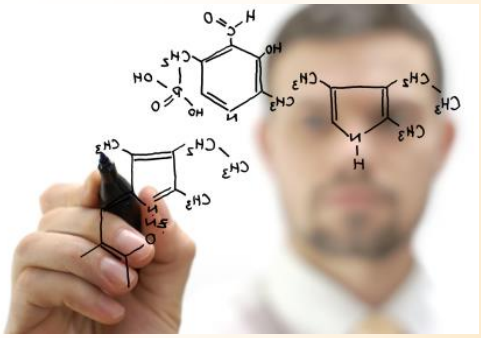
At the drive level, several technologies are brought to bear to reduce the effects of debris and contaminants.

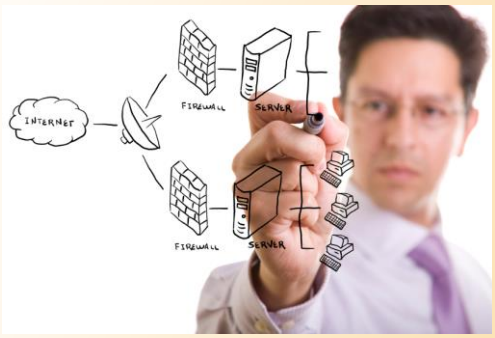
Nearly every high performance tape subsystem has a built in head cleaner. Its purpose is to clean loose debris off the surface of the head, maintaining the head-media interface integrity. In general, it is highly effective at cleaning the head and preventing the transfer of loose debris to additional cartridges. It is ineffective however at removing adherent debris. Nothing short of a highly abrasive diamond tape is effective at removing adherent, baked on debris.

Second, the error correction algorithms are typically well designed. They tend to spread the data bytes out over the surface of tape – down tape and across tape thereby providing good protection against defects and a certain level of debris. It takes a sizable quantity of debris to actually generate an unrecoverable error.

Third, the drives typically have a fairly robust error recovery strategy programmed in – including shuttling tape back and forth, "scrubbing" the head, etc.

Additionally, most drives monitor error rates and error recovery activity to execute and or request preventative maintenance. Preventative maintenance can include the






**Error Recovery Strategy**

Most devices have a strategy and algorithms built in that tell the drive what to do in the case that data cannot be read or written. Over time these algorithms have become very robust and detailed. A drive manufacturer never wants to abort a customers' job unless there is no other option.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head clean, running a cleaning tape, or perhaps calling for field service if performance is too far off nominal.

Some operating systems will call for a drive swap (moving tape from one drive to another) as part of the system level error recovery. In certain cases, this can save a customers' job from being aborted.

## Looking Forward[20, 21, 22]

Looking to the future is very exciting. With new media formulations coming on line, demonstrations of areal density capabilities between 29.5 Gb/in$^2$ and 45 Gb/in$^2$ have already been documented, providing the possibilities of many new generations of products.

Linear densities will increase - modestly. The head- media interface separation distance will limit advances in linear density. Disk technology is just breaking through the 1 million FCI marker. It is doubtful tape will reach that goal in the near future. Most likely, tape will not see linear densities above 750 KFCI without radical changes in tribology, head materials, and media chemistry. While sputtered thin film tape technology can be achieved, it is far from being cost effective.

Track densities will also increase. Track density increases will be the primary thrust for increasing capacity moving forward, due to the limitations in linear density. Today, written track widths are less than 10 microns. Next generations will have tracks about 5 microns or less. The subsequent generation will be about 2.5 microns – all assuming a 2:1 progression in storage capacity as announced from the LTO consortium.

Limiting factors to track density enhancements will be media dimensional stability, tracking (servo) capability, and backward read capability of older formats. Additionally, there will be constraints placed on the consistency of media coating thicknesses – much more so than we observe today.

Head-media separation requirements will decrease, again due to the increases in linear density. As a result, sensitivity

**Tracking Servo Techology**

With the advent of modern serpentine tape systems, multiple passes are required to fill a given tape. To properly position the head relative to the desired position on tape, a closed loop control system is utilized to achieve very tight position tolerances and control. This system is referred to as tracking servo – it tracks the servo tracks written on tape.

**Tribology**

Tribology is the study of tribo-electric forces between materials that affect the nature of materials moving in relation to one another.


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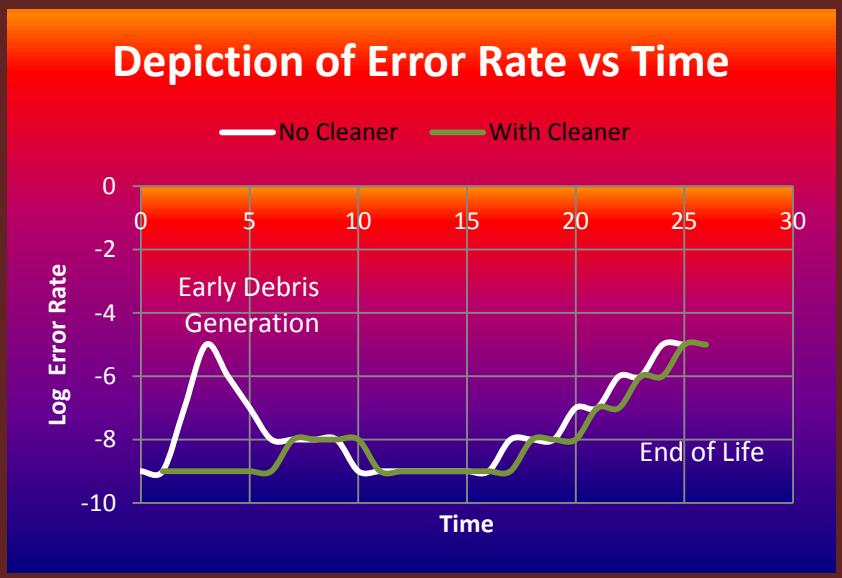
to debris and contaminants will increase. Cleanliness will indeed become a paramount issue.

Media abrasivity will become more difficult to maintain over extreme combinations of temperature and humidity. Therefore, requiring the tape to keep the heads clean will be more difficult to achieve. With increasing linear densities, physical wear of the recording heads will not be tolerated as well, and must be addressed. Additionally, more end to end passes on tape will be required to fill a volume.

Potential increases in early life drive failures could occur if the debris situation is not addressed. Reducing the sensitivity of a given drive manufacturer to various media manufacturers tape formulations will become more important.

## What is Needed?

Remember that plot on page 9?




What if a solution were to be engineered that could eliminate the early error rate degradation due to debris (first half of the plot above)? The overall system performance would be significantly enhanced. This enhancement would most likely be observed in the form of improved error rates, improved archival data quality, and improved system

Over the years, many technologies have been applied to cleaning tape. Among some of the more popular are:

- Cleaner Blades used vacuum assist "vacuum" debris from the surface of the tape.
- Rotating cloth material cleaners used to "wipe" debris from the surface.
- Front side and back side wiping systems.
- Systems in-situ to the tape drive.
- Systems external to the tape drive (auxiliary cleaners).

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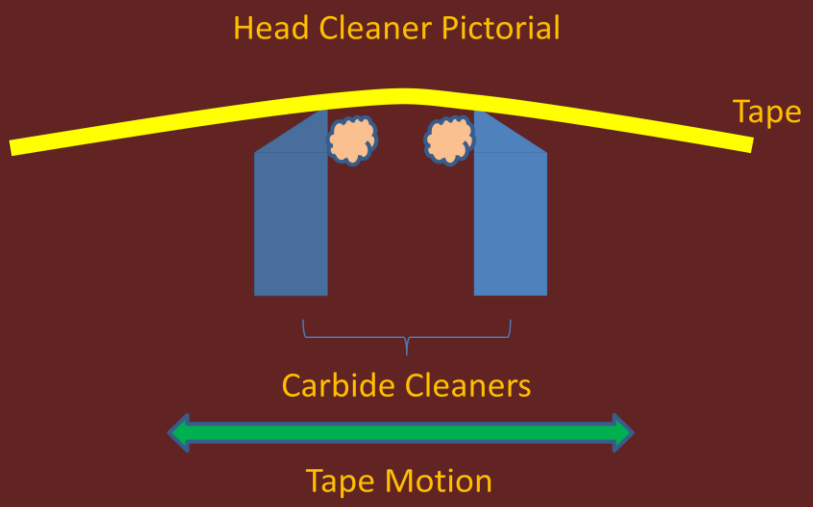
throughput since the drive would not have to deal with the early debris situation.

While modern systems are robust, their performance can be compromised due to the situations described above, reducing system performance sig nificantly.

One method to address the debris situation is to institute a tape cleaner function. This is not a new idea. The concept and application has been around for decades. In fact many tape drives utilized tape cleaners in past generations.




Examples of products that used tape cleaning technology are 9 track PE/GCR drives from the 70's, IBM 3480/3490 from mid 1980's, StorageTek 4480, 4490, 9490 drives from the 80's and 90's. The majority of these devices utilized Tungsten carbide cleaner blades. Cleaner blades disappeared in the mid 90's when the drive form factors were significantly reduced. No longer was there a vacuum supply to aid the cleaner.

There was a form of tape cleaner in drives from the 90's – it was the transverse slots found in many recording head designs. These transverse slots were intended to control the head-media separation distance. Additionally, they would fill up with debris, and when the cartridge was ejected, the heads were brushed removing the debris. Modern drives operate under much reduced tension and head contact pressures. Hence their effectiveness as tape cleaners is potentially reduced.

Early Tape drives contained tape cleaners. They operated at very low linear and track density compared to today. Additionally, they operated at higher tape tensions.

Given today's drive technology, it is unlikely that an in-situ cleaner would be required. However, it could be very beneficial to have an automation mounted tape cleaner solution that could be utilized for periodic maintenance and error recovery strategy.

Furthermore, having a robust cleaning prior to first use of media could benefit reliability, infant mortality of drives, and enhanced archivability reliability of tape.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Carbide is potentially a good choice in that as tape moves over the cleaner, it wears slowly, but does not fracture. With proper design of attack angles, the blades are self sharpening, requiring very little maintenance, other than occasional cleaning.

Experience with ceramics indicate that they are very effective – in the beginning. However, as they wear, the cleaner tips tend to fracture resulting in a rough, jagged surface. Hence the ceramic cleaner moves from being an aid to a severe detriment – it generates debris and damages tape.

There are additional potential benefits to the use of tape cleaners – the early life error rate degradation with new (fresh, or "green") tapes should be significantly reduced if not eliminated. Less debris will be wound into the tape pack reducing concerns over long term storage.

Additionally, WORM (write once read mostly) applications can benefit – getting the debris off the surface prior to recording should simply enhance the recording quality and archivability of these special tapes.

By following the recommendations to the right, the integrity of tape libraries can be enhanced.

That said it is paramount that the cleaner does not degrade the tribological properties of the media, especially the environmental performance and coating quality. Improvements would be beneficial, and less demanding on the head design.

Application of an intelligent cleaning strategy is paramount to maintaining high integrity data. It would be advisable for the cleaning history of the tape to be logged and tracked.

Maximizing Data Quality

To maximize quality of data stored on tape, execute the following recommendations:

1. Follow the guidelines for environment suggested by NML (National Media Lab) and Recording Archivists Assn[23, 24].
2. Control airborne debris by proper installation of drives and libraries away from sources of contaminants such as high volume laser printers, impact printers, cleaning systems, etc.
3. Allow tape to acclimate in the environment for 24-48 hours prior to usage in a tape drive.
4. Follow the cleaning recommendations of the drive/library manufacturer.
5. Always buy new, fresh tape from a reputable source.
6. Don't over extend usage of tape – follow the life cycle recommendations of the manufacturers.
7. Actively manage the quality of your tape library – remove and replace any suspect volumes of tape long before they become an issue.


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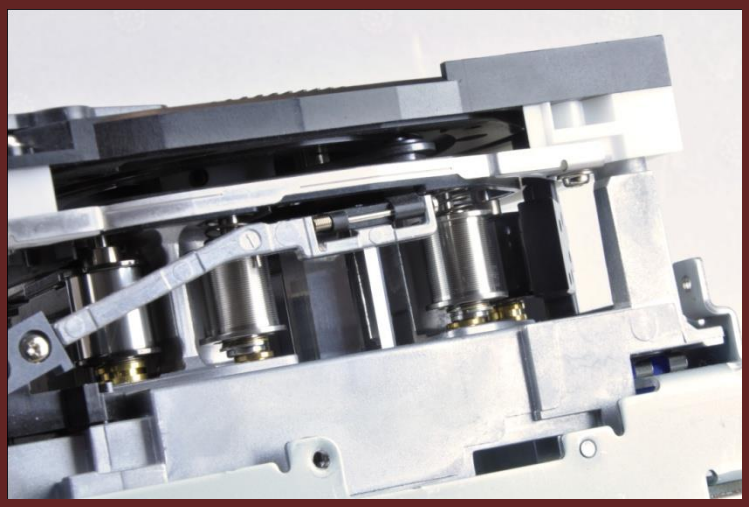
# Recent Announcements

Recently, Spectra Logic Corporation has announced an exciting new product/service – "CarbideClean™." It has the potential to address many of the issues presented herein. Coupled with their automation strategy, Spectra Logic is positioned to be the library provider of choice in the future.

With CarbideClean,™ media purchased from Spectra Logic will receive special attention prior to shipping, removing a majority of the loose debris not caught by the media manufacturers at time of cartridge assembly.

In addition, it will provide for a library in-situ cleaning station, and the ability to track cleaning intervals for every cartridge in their library. This feature, coupled with "intelligent clean"™ algorithms should provide enhanced protection of customers data.



Photo's courtesy of Spectra-Logic Corporation © 2011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# About Spectra Logic Corporation

Spectra Logic Corporation is perhaps the only manufacturer in the industry focusing on data backup and archive to tape, with an emphasis in innovations in storage including the CarbideClean feature. While other companies were being bought and sold, and focusing on disk for backup and leaving tape behind, Spectra Logic made continuous and ingenious advancements that others are only now scrambling to catch up with. With a focus on customers and on quality, and with products that are made in America, Spectra Logic has continued to do very well, and earn very high quality ratings.

In the 2010 Storage Quality awards, Spectra Logic swept all categories, outranking competing midrange and enterprise tape library solutions from IBM, Oracle, Hewlett-Packard and Quantum by substantial margins.  End-user respondents gave Spectra Logic the highest scores recorded to date in the Quality Award survey of tape libraries, and the company's overall score bested its nearest competitor in the enterprise category by nearly a full point.  An impressive ninety-five percent of enterprise respondents said they would make a repeat purchase with Spectra Logic, reflecting loyalty and customer satisfaction, and outpacing responses for all other vendors.

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## About the Author

Mr. Joe Jurneke has 38 years of engineering experience in storage peripherals. 12 years in Disk drive development, 26 in tape systems. He has contributed both as an individual technical contributor, and as a technology manager/Director, with 28 years of management experience. He has played a critical role in the development of 10 enterprise level world class storage products, a multitude of mid range products, and has spent 8 years driving head and media technology for tape products providing advanced technology 2 to 5 years ahead of the product requirements. Mr. Jurneke holds as inventor/co-inventor 9 US patents, 4 others pending. He also has received 2 inventor recognition awards, and the StorageTek Chairman's quality award 1996.


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