Contamination Control and Mitigation for Iomega’s REV™ Technology

Iomega’s three-fold strategy for contamination control:
start clean, stay clean and manage the remainder

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Introduction

Iomega’s revolutionary Removable Rigid Disk (RRD) technology provides the speed, reliability, and ease-of-use of a hard drive with the portability and expandability of tape and optical media. While based on standard hard drive components, the removable Iomega RRD disk contains only the magnetic media and spindle hub and motor for greater durability – all the sensitive drive heads and electronics remain in the drive itself. Both the drive and disks are sealed by a unique shutter mechanism designed to keep the heads and media in a virtual “clean room” environment. Advanced air filtration, automatic head cleaning, and robust two-stage error correction are employed to ensure high data integrity and reliability.

The Iomega® REV™ 35GB/90GB* drive system is the first of the company’s RRD-based family of products. With its high speed, capacity, and support of removable media, the Iomega REV products are the ideal solution for desktop and server-level backup as well as high-capacity, portable storage applications.

This paper discusses contamination control for a removable cartridge disk drive system that utilizes rigid media. The paper summarizes Iomega’s extensive findings and analyses as well as explains how the Iomega REV products have been designed to prevent and eliminate contamination. The research that is summarized in this document provides insight into Iomega’s continuing focus on technological innovation to ensure that its RRD platform minimizes contamination and mitigates any contamination that might occur during operation.

Iomega’s Technical Heritage in Removable Storage

In developing RRD technology, Iomega undertook advanced engineering efforts to determine the feasibility of making a high capacity, state-of-the-art removable rigid disk drive. The focus was centered on four areas:

1. Keeping contamination out of the system;
2. Dealing with contamination that enters the system, or is generated by the system;
3. Determining how head fly height is affected by contamination, whether the effects can be detected, and if affected, return the fly height to normal; and
4. Evaluating what kind of errors result from contamination, how these errors can be corrected, and what disk format mitigates these errors.

Iomega used off-the-shelf 2.5-inch hard disk drives (HDDs) as test beds to explore these important questions. Since these drives were working,

* Compressed capacity assuming 2.6:1 data compression with “high” compression on Iomega Automatic Backup Pro software. Capacity may vary and is data and software dependent.
sealed systems, any problems arising in experiments could be attributed to the introduced test conditions, which usually entailed some form of contamination.

The knowledge gained from these exercises, combined with lessons learned from Iomega’s first rigid media-based removable storage product, the Jaz® drive, encouraged Iomega to initiate a full product development program. The resulting RRD technology is now incorporated into the new REV drives and disks.

From the beginning, it was clear that product design efforts had to converge on a top priority: contamination control and mitigation. In designing RRD architecture and features, Iomega adhered to a straightforward, three-fold strategy:

1. Start clean,
2. Stay clean,
3. Manage the remainder.

The first two elements involve keeping contamination out of the system; the third references how to deal with contamination that enters the system by using both a patent-pending head cleaning system and a powerful two-level error correction code (ECC) system.

1. Start Clean

REV technology strategically leverages the knowledge and experience of the HDD industry. To start clean, Iomega selected materials and cleaning processes that are standard for HDDs. Iomega worked with suppliers that have HDD experience and typically use sophisticated material analysis capabilities with special attention given to both particulate and chemical cleanliness. Leveraging the experience of HDDs and Jaz drives, Iomega has achieved positive out-gassing test results from these efforts addressing chemical cleanliness. Operational testing at 55 degrees Celsius and 80 percent relative humidity (RH) for a period of 120 hours, and non-operational soak testing at 32 degrees Celsius and 90 percent RH for 168 hours, showed no residue transfer to the heads or media. This standard HDD testing procedure indicates a very clean design. Part specifications for the REV products call for consistent control of the component cleanliness.

2. Stay Clean

While Iomega is committed to its strategy to start clean, the company acknowledges that the removability aspect of the RRD design introduces greater potential for contamination than that of a sealed HDD. RRD technology incorporates a unique cartridge design, sealing technologies, air and absorbent filtration mechanisms as well as corrosion control to address specifically the added complexities of hard disk removability.
2a. Disk Design: Sealing and Debris Generation

The REV cartridge is designed to maximize cleanliness from particulates, which requires both effective cartridge sealing and minimization of debris generation during cartridge insertion and ejection. The objective of the REV cartridge design is to minimize moving mechanisms, and subsequently reduce any debris potentially generated by the moving parts.

An analysis of Iomega’s Jaz technology design revealed two locations the Jaz cartridges could not be fully sealed: the large motor hub access hole, or spindle hole, and the large head access hole. Conveniently, the REV design completely eliminates the need for the spindle hole, thus radically changing the entire design concept for head access.

The Spindle Motor is in the Cartridge

REV technology design avoids the problem of contamination entering the disk through the motor access hole by incorporating the motor inside the cartridge, instead of as a part of the drive. This important cartridge design innovation eliminates the need for both a large motor access hole and an additional mechanism to block such a hole. Also, unlike drives which use an anti-gyro mechanism to lock the disk/hub to the motor to avoid separation during system motion, possibly resulting in rubbing and debris formation, the new REV drive does not require an anti-gyro mechanism. The in-cartridge motor in the REV disk removes the challenging disk/hub to motor hub coupling process.

Simplicity of Design: The Key to the Cartridge Shutter Mechanism

The REV cartridge shutter is a simple rotating door, with two pivots and an elastomeric seal. The shutter seals the head access hole in front of the cartridge, minimizing sliding interfaces. Iomega believes that this is an improvement over sliding head access shutters used in other products, which can potentially generate debris during operation.

The cartridge plastics design has tight fitting interlocking circular walls on both the bottom and top halves of the cartridge. These two walls overlap each other upon assembly and a labyrinth effect seals out particulates by creating a high-resistance path entrance to the clean area of the cartridge. As a result, particles now tend to drop out of the air leakage flow before they can be transported through the labyrinth. In addition, REV cartridges have a steel motor base-plate that interfaces with the plastic bottom shell half via closed foam seals. The result contributes to the overall sealing of the cartridge by eliminating potential leak paths.

As a result of these design improvements and the attention to cartridge sealing, REV technology demonstrates a greatly improved cartridge leak rate when compared to the older Jaz technology. A prototype REV cartridge (P4) that is not yet inserted into a drive is pressure tested. The improvement over Jaz technology, which dates back to the mid-1990s,
can be seen in the following graph, which highlights the effectiveness of the REV cartridge at sealing and holding internal pressure.

![REV Cartridge Leak Rates](image)

**2b. Drive Design: Sealing and Debris Generation**

In addition to the cartridge mechanisms, the drive architecture is created with sealing and debris generation as top priorities. The drive’s actuator assembly is housed in a clean area toward the rear of the drive. In front of the clean area is a section known as the “gray” area. A drive shutter separates and seals the gray area from the front-most section of the drive, which is the area most exposed to contamination. This design creates three regions that are progressively cleaner from front to rear. In addition, the drive shutter has an elastomeric seal, which protects the gray and clean areas when the cartridge is not inserted.

Two other features keep the drive clean when no cartridge is in place. A front flapper door blocks outside debris from entering the drive. Also, the drive is designed as a sealed five-sided box such that the airspace in the drive interior is “dead”. This design prevents potential pressure differentials that could create airflow as well as movement of contamination into the drive. Pressure differentials can be caused by computer cooling fans or other similar devices that move air in proximity to the installed REV drive.

Insertion mechanisms on the REV drive have been designed to minimize debris generation and to operate in the front and gray areas, not in the clean actuator area. Upon inserting the cartridge, the cartridge shutter opens momentarily in the gray area to allow access to the disk. When the cartridge is fully inserted and in operating position, another drive
Contamination Control

Seal mates with the cartridge front surface to form an interconnected drive/cartridge clean chamber. The drive seal interfaces with the same cartridge surface that the cartridge shutter seal interfaces with when the cartridge is out of the drive. Pressure testing of this interconnected chamber reveals minimal leakage, as demonstrated in the following Leak Rate graph. Again, Jaz drive performance is shown for comparison with P2 and P4 representing REV prototype versions.

![Leak Rates (Delta Pressure vs Flow Rate)](image)

When the cartridge is ejected, a DC motor and gear train operate an ejection mechanism. The DC motor, gear train and related mechanical linkages all exist outside of the five-sided box. Therefore, any debris generation caused by these components cannot be exposed to the media and heads.

2c. Clean Chamber Air Filtration and Absorbent Filtration

Although the cartridge shutter is opened only momentarily, it is possible that some outside air could enter the clean area upon disk insertion. Once a cartridge is inserted into a drive, the clean chamber air is filtered in a purge process before the heads are loaded onto the disk. Two filters are placed in the cartridge, one close to each disk surface, with special attention given to pressure differentials that pump inside air through the filters. The following schematic diagram displays the filter concept.
As shown in the Typical Cleanup chart below, testing has verified that the filtration system is effective and that the inside environment cleans up quickly. The purge cycle is planned to be seven seconds in duration.

The cartridge has an internal absorbent device that helps manage relative humidity (RH). It can remove moisture in times of very high RH and can release some moisture during very low RH conditions. This absorbent filter is also designed to remove volatile organics and acid gases from the system. By effectively removing these contaminates from the system, sensitive components within the drive are protected.

The following Desiccant Effectiveness graph indicates how adding the absorbent mechanism protects the cartridge. An accelerated test was used to accumulate the data and illustrate the effects of this desiccant pouch on relative humidity inside a cartridge that is open to the environment.
The following photo shows placement of one filter and desiccant in the cartridge shell:

![Placement of filter and desiccant in cartridge](image)

2d. **Media, Corrosion and Contamination Sensitivity**

Of course, part of staying clean is avoiding corrosion, particularly on the media itself. REV disk corrosion testing has been conducted using Battelle mixed gas tests. Battelle testing exposes components to
corrosive atmosphere that accelerates real-world corrosion effects. Using these tests, textured aluminum substrate disks were found to exhibit some corrosion sites, which propagated from the surface texture lines. However, REV media utilizes glass substrate, and studies at Iomega and in the HDD industry reveal that glass media have distinct advantages over aluminum for corrosion resistance. In addition, glass was found to be resistant to particles embedding themselves into the disk and causing hard errors as well as potential sites that could damage a head read/write element. This problem has been encountered on other removable products where aluminum substrate media was used. With glass, particles tend to disintegrate and are flushed through the system with little, if any, perceptible damage to the disk. In Iomega’s experience, glass substrate media is very robust in resisting damage from particles.

3. Manage the Remainder: Head Cleaning and Two-Level ECC

Even with an exemplary strategy for starting and staying clean, Iomega recognizes that the removable nature of RRD technology means the REV drive and disk environment will not be as clean as a sealed HDD. Advanced work with off-the-shelf 2.5-inch HDDs show that head cleaning, fly height monitoring and powerful ECC all can mitigate the effects of contamination.

To study these effects, the HDD heads and media were exposed to various levels of foreign contamination to study the response of the system and the nature of the errors created. The next five sub-sections describe the exposed HDD errors encountered in contaminated environments, and identify the root causes of the errors. In addition, a review is provided of REV features that mitigate these types of errors, including head cleaning, fly height monitoring and two-level ECC.

3a. Error Classification

Early investigations of REV technology revealed that the majority of errors observed could be classified as a hard write error caused by position error signal (PES), a hard read error caused by a poor write or poorly read data. A very low incidence of thermal erasures and media damage were observed, as shown in the histogram below.
**Write Errors Due to Excessive Position Error**

When an HDD is exposed to a contaminated environment for a prolonged period, the drive starts to encounter write errors due to poor PES. While PES faults during writing occasionally happen in hard drives, and can be caused by a number of factors, the occurrence is much higher in a contaminated environment. It is believed that these errors are caused when the head accumulates debris. The debris causes the head to fly lower until the slider begins to contact the disk. The resulting disturbance cause track-following problems and fly height variation.

**Read of Poorly Written Data**

Proper writing of the magnetic media requires correct and constant spacing between the head and disk. Particles moving through the head/disk interface can cause the heads to temporarily fly high. If this happens during a write, the result can be poorly written data. These kinds of errors can range in size from a few bytes to multiple sectors.
Poorly Read Data

Improper fly height, either too high or too low, also can affect adversely the drive’s ability to read properly written data.

Thermal Erasures and Media Damage

A small number of thermal erasures and media damage were observed in the advanced testing scenarios. Thermal erasures occur when a hard particle is trapped between the head and media and generates enough heat to alter the state of the magnetic recording. Thermal erasures generally span multiple tracks but are limited to one data or servo sector per track.

Media damage is physical damage to the media due to mechanical contact of the media by either the heads or a hard particle. The few observations of media damage were limited to one sector and one track.
Preamp output shows media defect causing a hard error.

Error Mitigation

The hard write errors due to excessive PES and the poor reads of good data were attributed to debris build-up on the heads. The corrective action for these errors is head cleaning, as described below.

High fly writes, media damage, and thermal erasures are addressed by a combination of sampled fly height monitoring and two-dimensional ECC, which is also described below.

3b. Head Cleaning

The open HDDs were run in contaminated environments as class 300,000 ppm. To put this into perspective, class 300,000 is a level that is very unsafe for human exposure. A typical office environment would measure class 20,000 ppm. Open drives in class 300,000 ppm generally would have trouble operating after approximately 24 hours. The interesting and important finding was that the heads of these units could be cleaned and the system restored to the original operating condition, as measured by soft error rate. Most interesting, this recovery was shown to be repeatable, as the chart of Head Cleaning vs. SER below illustrates.
The cause of soft error rate variation was determined to be the accumulation of contamination on the air-bearing surface (ABS) of the head, which affected fly height. Removing the contamination restored the head operation. Also, the testing revealed that certain ABS regions were more sensitive to these accumulations. The invention and final design of the REV head cleaning system leverages the findings of this early work. For instance, the REV head cleaner is designed to provide special effectiveness to critical ABS elevation changes or steps that experiments have shown to have significant impact on head fly height.

The head cleaner is a special textured surface. Effective head cleaning requires specific simultaneous motion of both the head and the textured surface. Studies have been completed to optimize the motion’s direction, frequency and amplitude.

The heads are sent to this surface for cleaning by a firmware command, which is triggered by monitoring certain parameters within the drive. The timing for head cleaning is a critical technology design factor. In the case of contamination accumulation, if the heads are not cleaned often enough, fly height will be affected. Fly height may decrease, ultimately causing head-to-disk contact and head or disk damage. If the head is cleaned too often, the cleaner may wear out and lose its effectiveness. The system has been designed to monitor key fly height metrics. When limits are exceeded, the heads move to the cleaning material and the drive executes the cleaning routine. After cleaning, the drive checks the fly height metrics to determine whether cleaning was adequate. Below is a chart indicating the change in this metric before and after head cleaning. The data shows the metric returns to normal operating range and the drive soft error rate also returns to normal.
3c. Sampled Fly Height Monitoring

Monitoring the fly height of the head can minimize the effects of transient spacing variations. If a fly height event occurs during writing, the data can be rewritten or reallocated, if necessary. Continuous monitoring of fly height would be difficult and costly, so REV drives use a sampled system. During each servo sector, the drive measures the properties of the servo data to determine fly height. If the values of these measurements or the change from sample to sample exceed the predetermined limits, the drive detects a high fly condition and reacts accordingly.

The advantage of a sampled system is that it is simple to implement and adds practically no cost to the drive. The disadvantage is that it is only sampled at each servo sector, and high fly events shorter than the servo sector-to-sector time may go undetected. This concern is addressed in the design of the ECC system.

3d. Two-Level ECC System

REV drives incorporate a two-dimensional Reed-Solomon product code error correction code (RSPC ECC) to enhance data reliability. Considered superior to the correction used in HDDs and previous Iomega products, two-dimensional ECC lets the drive correct whole sectors compared with only a number of bytes in error. The inner, or sector correction, similar to correction used in hard drives today, can correct up to 24 bytes in a 512-byte sector on-the-fly. This correction is the first line of defense against errors. If the inner correction can fix the error, then the outer correction is never used. The outer correction, also known as block ECC, corrects only whole rows and only those that are uncorrectable by the inner ECC. Since the locations of the errors are known, the correction ability of the block ECC is equal to the number of parity sectors included with the data.
As mentioned above, the correction capability required from the block ECC is dependent on the capabilities of the fly height detection. Because REV drives use a sampled system, the block ECC must be able to correct the maximum amount of data that can be stored between two servo sectors. For the 35GB REV drive, there are 6 data sectors per servo sector at the outer diameter (OD). Therefore, the block ECC was designed to correct up to six sectors per ECC block. The size of the ECC block was chosen to be 128 sectors plus six parity sectors, which results in 64KB of user data. This value was chosen as a compromise between format efficiency, performance and convenience when working with a Universal Disk Format (UDF) file system.

With the combined power of the inner and outer correction, and depending on the error distribution, a string of 3,072 bytes to 6,000 bytes in error can be recovered from each 64k ECC block as shown below.

![REV ECC Configuration](image)
Conclusion

Iomega’s REV removable hard disk drive system has been designed with a comprehensive blend of valuable features that control and mitigate the effects of contamination. These designs are based on an advanced technology effort that characterized the response of HDDs to introduced contamination. The result of extensive research and testing led to the development of a simple contamination strategy: start clean, stay clean and manage the remainder with head cleaning and a powerful two-level error correction code.

REV components are clean and minimize out-gassing since they leverage standard HDD industry practices for material selection and cleaning processes. In-depth testing reinforces the reliability of the REV architecture in meeting its goal to seal the drive and cartridge effectively. Design objectives to minimize debris generation and filter entrained contamination also have been met. Iomega’s patent-pending head cleaning system and unique cleaning indicator routine provide enhanced protection from contamination. Finally, REV technology uses a powerful ECC to provide a final layer of data protection. In combination, these features and the attention to contamination control enable REV drives and removable disks to function with extremely high levels of quality and reliability.

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