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Technology**Paper**

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Get S.M.A.R.T. for Reliability

The Emergence of Reliability-Prediction Technology

Disc drive manufacturers are dedicated to improving product reliability. This idea seems fitting. Reliability is a concept we seek in our daily lives. We want cars that are reliable. Reliable people make good friends and good employees. We naturally expect things to perform well. Although reliability cannot always be predicted in people or cars, disc drive manufacturers have taken a giant step toward predicting reliability in disc drives through Self-Monitoring, Analysis and Reporting Technology (S.M.A.R.T.).

Computer users today have great expectations of data-storage reliability. Many users do not even consider the possibility of losing data due to a hard disc drive failure. Even though continual improvements in technology make data loss uncommon, it does occur. Reliability-prediction technology is a way to anticipate the failure of a disc drive with sufficient notice to allow a system, or user, to back up data prior to a drive's failure. S.M.A.R.T. is reliability-prediction technology for both ATA and SCSI environments. Pioneered by Compaq, S.M.A.R.T. is under continued development by the top five disc drive manufacturers in the world: Seagate, IBM, Western Digital Corporation, Maxtor and Quantum Corporation.

The Evolution of S.M.A.R.T.

Reliability-prediction technology emerged from the need to protect mission-critical information stored on disc drives. As system storage capacity requirements increased and multiple disc array systems appeared, industry leaders identified the importance of creating an early warning system that would allow enough lead time to back up data if failure was imminent. To understand how S.M.A.R.T. evolved, it is necessary to look at S.M.A.R.T.'s roots, which are based in technology developed by IBM and Compaq.

IBM's reliability-prediction technology is called Predictive Failure Analysis (PFA). PFA measures several attributes, including head flying height, to predict failures. The disc drive, upon sensing degradation of an attribute, such as flying height, sends a notice to the host that a failure may occur. Upon receiving notice, users can take steps to protect their data.

Some time later, Compaq announced a breakthrough in diagnostic design called IntelliSafe. This technology, which was developed in conjunction with Seagate and Quantum, monitors a range of attributes and sends threshold information to the host software. The disc drive then decides whether an alert is warranted and sends that message to the system, along with the attribute and threshold information. The attribute and threshold level implementation of IntelliSafe varies with each disc drive vendor. However, the interface, and the way in which status is sent to the host, are consistent across all vendors.

Compaq placed IntelliSafe in the public domain by presenting its specification for the ATA environment, SFF-8035, to the Small Form Factor Committee on May 12, 1995. Seagate quickly recognized that reliability-prediction technology offered tremendous benefits to customers and researched the possibility of making a version available to other system OEMs, integrators and independent software vendors. Seagate was joined by IBM, Quantum and Western Digital in the development of this new version, appropriately named S.M.A.R.T., which combines conceptual elements of Compaq's IntelliSafe and IBM's PFA.

S.M.A.R.T. Features

Features of S.M.A.R.T. technology include a series of attributes, or diagnostics, chosen specifically for each drive model. Attribute individualism is important because drive architectures vary from model to model.

Attributes and thresholds that detect failure for one model may not be functional for another model. Comparing different models of cars helps illustrate this point. Some cars are equipped with four-wheel drive, but others, like a Cadillac, are not. In other words, the architecture of the drive determines which attributes to measure and which thresholds to use. Although not all failures can be predicted, we can expect an evolution of S.M.A.R.T., as technology and experience sharpen our ability to predict reliability. Subsequent changes to attributes and thresholds will also occur as field experience allows improvements to the prediction technology.

Some Failures Are Predictable and Some Are Not

A disc drive must be able to monitor many elements to achieve comprehensive reliability-management capability. One of the most crucial elements is understanding failures. Failures can be seen from two standpoints: predictable and unpredictable.

Unpredictable failures, such as electronic and some mechanical problems, occur quickly. For example, a power surge may cause chip or circuit failure. Improvements in quality, design, process and manufacturing can reduce the incidence of nonpredictable failures. For example, the development of steel-belted radial tires reduced the occurrences of blowouts common among older flatwall "rag" tire designs.

Predictable failures are characterized by degradation of an attribute over time, before the disc drive fails. This creates a situation where attributes can be monitored, making it possible for predictive-failure analysis. Many mechanical failures are typically considered predictable, such as the degradation of head-flying height, which would indicate a potential head crash. Certain electronic failures may show degradation before failing, but more commonly, mechanical problems are gradual and predictable. For instance, oil level is a function, or "attribute" of most cars that can be monitored. When a car's diagnostic system senses that the oil is low, an oil light comes on.

The driver can stop the car and save the engine. In the same manner, S.M.A.R.T. allows notice to start the backup procedure and save the user's data.

Mechanical failures, which are mainly predictable failures, account for 60 percent of drive failure. This number is significant because it demonstrates a great opportunity for reliability-prediction technology. With the emerging technology of S.M.A.R.T., an increasing number of predictable failures will be predicted, and data loss will be avoided.

How Attributes Are Determined

S.M.A.R.T. technology resembles a jigsaw puzzle—it takes many pieces, put together in the right way, to make a pattern. Understanding failures is one piece of the puzzle. Another piece of the puzzle is the way attributes are determined. Attributes are reliability-prediction parameters, customized by the manufacturer for different types of drives. To determine attributes, Seagate design engineers examine returned drives, consider the design points and create attributes to signal various types of failures. Information gained from field experience can be used to predict reliability exposures, and attributes can be incorporated into the new reliability architecture.

Although attributes are drive-specific, some typical characteristics are:

- Head flying height
- Data throughput performance
- Spinup time
- Re-allocated sector count
- Seek error rate
- Seek time performance
- Spin try recount
- Drive calibration retry count

The attributes listed above illustrate typical kinds of reliability indicators. Ultimately, the disc drive design determines which attributes the manufacturer will choose. Attributes are therefore considered proprietary because they depend on drive design.

The Two S.M.A.R.T. Specifications

S.M.A.R.T. emerged for the ATA (IDE) environment when SFF-8035 was placed in the public domain. SCSI drives incorporate a different industry-standard specification, as defined in the ANSI-SCSI Informational Exception Control (IEC) document X3T10/94-190. Seagate's S.M.A.R.T. System program includes both industry-standards, making S.M.A.R.T. technology available for both products with either ATA or SCSI interfaces.

The S.M.A.R.T. system technology of attributes and thresholds is similar in ATA and SCSI environments, but the reporting of information differs.

In an ATA environment, software on the host interprets the alarm signal from the drive generated by the "report status" command of S.M.A.R.T. The host polls the drive on a regular basis to check the status of this command, and if it signals imminent failure, sends an alarm to the end-user or system administrator. This allows downtime to be scheduled by the system administrator to allow for backup of data and replacement of the drive.

This structure also allows for future enhancements, which might allow reporting of information other than drive conditions, such as thermal alarms, CD-ROM, tape or other I/O reporting. The host system can evaluate the attributes and alarms reported, in addition to the “report status” command from the disc. Generally speaking, SCSI drives with reliability-prediction capability only communicate a reliability condition as either good or failing. In a SCSI environment, the failure decision occurs at the disc drive, and the host notifies the user for action. The SCSI specification provides for a sense bit to be flagged if the disc drive determines that a reliability issue exists. The system then alerts the end-user or system manager.

Seagate Refines S.M.AR.T. Support

Since its inception nearly five years ago, S.M.A.R.T. has undergone vast improvements. Seagate has added the following S.M.A.R.T. features for an even more robust implementation.

Enhanced S.M.A.R.T.

Drive Self-Test
Drive self-test (DST) reports the operational status of the hard drive, giving the end-user another tool to help diagnose the root cause of a suspected hard drive problem. Upwards of 40 percent of drives returned to Seagate are tested and determined to be fully operational drives. Therefore, there was some other root cause for the drive return, such as a virus or software bug.

Introduced in 1999, DST’s diagnostic technology will continue to play a role in Seagate’s ATA drive firmware. DST expands on S.M.A.R.T. by predicting hard-drive failure, and by determining whether a drive is functioning correctly. Be advised that hard drive failure prediction is a complex challenge and there are certain classes of failures that are simply unpredictable.

The diagnostic tests embedded in the firmware were collectively developed between Seagate’s engineering and reliability organizations. Compared to a generic PC-based, software-only diagnostic that tests all hard drives in the same manner, DST can change in each new drive family and executes precise tests that are only directly accessible by the drive firmware. There are two types of DST Tests:

DST Quick Test
A two-minute test targeted at quickly determining the operational status of the drive. As part of the testing, it reads at least the first 1.5 Gbytes of the drive.

DST Extended Test
In addition to other low-level testing, this test completely scans the media. The time required to complete this test depends on the capacity of the drive.

S.M.A.R.T. Error Logging

The S.M.A.R.T. Error Logging technology saves a record of the most recent errors reported by the drive to the host PC with some additional data used to analyze the error condition. This technology is primarily used by Seagate engineers during drive development to quickly identify and fix design issues before a drive goes to production. It also helps identify whether a drive could have been the root cause behind recent system failure.

S.M.A.R.T. Standards Supported

Currently, Seagate supports the following ATA specifications regarding S.M.A.R.T.:

- T-13 ATA/ATAPI-5 Standards document
- S.M.A.R.T. 2.0
- Offline Defect Scanning and Sparing (not in ATA/ATAPI –5)
- Enhanced S.M.A.R.T. (Drive Self-Test)
- S.M.A.R.T. Error Logging