Dynamic Optical Metrology for Production
or
(Test Economics 101)

by

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Abstract

As we evolve the technologies for producing higher density disk drives we find that there are three classifications of barrier; theoretical, technological and practical. Currently disks and drives are nowhere close to the theoretical barrier but we in the industry are experiencing manufacturing difficulties in producing high tolerance components that are suitable for "pseudo-contact" recording devices. Are we therefore reaching a practical or a technological barrier? We at THôT Technologies believe that the barrier is purely a practical one and new technologies should be examined to ease the manufacturing burden and help find ways of solving these manufacturing difficulties.

One of these new technologies is to optically scan the disks, not necessarily for the magnetic defects themselves, but perhaps for the cause of the defects, and as early in the manufacturing process as is feasible.

Definitions

<u>Burnish</u> - to polish, buff, smooth or put on a finish. Historically accomplished by the application of very fine polishing material (e.g. polishing tape) and/or flying a head over the surface at a very low height (e.g. half the glide height). Commonly accomplished today with specialty heads (e.g. "waffle heads", see Figure 1) that are run "in contact" across the surface.

<u>Glide</u> - to slip, flow or slide. A test for the mechanical performance of the disk presently limited to testing for asperities protruding above the local disk surface. Accomplished by flying a head over the surface to detect defects. Ultrasonic detection was replaced with embedded piezo transducer (PZT) heads and acoustic emission (AE) detectors.

<u>Certify</u> - to verify, assure, authenticate, accredit or confirm. Primarily a test to identify defective regions in the magnetic coating and extended to include the magnetic properties of the disk surface. Initially involved writing a high frequency pattern, reading it back and looking for pulses which fell below a fixed level. This test has grown to include percentage of missing pulse, extra pulse, positive and negative modulation, ID and OD amplitude, bit shift, overwrite and pulse width modulation.

Practical limitations

As required data densities increase, maximum defect size and the allowable numbers of defects both decrease. With this comes a concomitant decrease in both flying heights and track spacing which means that process handling and cleanliness become critical (and increasingly challenging) so as not to either miss critical defects at certification or to introduce additional defects into the disk. For example;

Burnish - This has become a micro-machining operation in the true sense. As the design of the burnishing tool (the waffle head) evolves to provide improved polishing capabilities, the need to assure removal of the cut material from the disk surface and from the cutting tool becomes more critical.
Consider the following;

1). Van der Waals forces work for particles in the range 0.003 - 050µm (0.01µ" - 2µ")[1]

2). Sub micron particles are hard to remove from surfaces[2].

3). Glide heights are heading ineluctably for <1µ" (0.025µm). Very definitely sub micron!

Glide - In low glide applications the head is in, or very close to, contact. The acoustic emission or piezo signal is so noisy it cannot effectively see "hits" especially when flying at heights <1µ". The reason for this is because the head instability, turbulence and/or disk flutter generates unwanted vibration which masquerades as "signal" and causes a deterioration in the signal-to-noise level (Figure 2). In addition, for low flying heads, defects under about 3µm in diameter generate about as much change in signal as a fly hitting your windshield at 60 MPH changes the speed of the car (Figure 3). Further, and more importantly, the glide head structure becomes part of the test. The resonant frequency of the slider, the air bearing design, gimbal mount and flexure properties, all interact with the disk runout, microwaviness and resonance to contribute to the inaccuracies of the measurement (Figure 4). As a result, glide test repeatability on low glide product has diminished well below normal acceptable standards (Figures 5a and 5b).

There is a new buzz word - "thermal asperity". This "asperity" is a glide hit but has as much to do with the head structure (air bearing design, gimbal mount and flexure properties), disk surface macro mechanical properties (microwaviness, flutter, resonance and runout) and operating characteristics (rotational speed, spindle design and base plate stability) as it does with disk asperities.

Certify - Disk certification has been forced by practical economics to become a statistical process. Several factors are at work here and all of them are throughput related;

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[1] "Tribology and Mechanics of Magnetic Storage Devices". B. Bhushan. p.p. 244-246 Springer-Verlag. New York

[2] "Contamination Control in Disk-Drive Manufacturing". P. Viswanadham. **Microcontamination** April 1987.

High FCI / BPI - While modeling and certain test criteria can predict the usability of a magnetic structure to achieve an increased flux change per linear inch, the demands of the drive industry outstrip the ability of the tester manufacturer to certify disks using similar channel characteristics. Heads designed for "leading edge technology" drives are very expensive until a specific design is being produced in volume. The economics of this "chicken - egg syndrome" dictate drive first, tester second. Rule - you cannot have the test capability until after you need it the most. Consider the cost of heads for maintaining test integrity in a typical magnetic certifier;

1). Typical cost of an MR test head ? $40 each (? $30 for thin film inductive)

2). Assume 1 change / shift

3). Assume 1 hour to change and re-calibrate the tester.

4). 2-4 heads per tester

5). Head cost is therefore $250 - $500 per tester per day.

6). What about the cost of the technician who has to change the heads and qualify more heads for use on the certifiers?

High TPI - The same conditions exist for increases in track density. Initial costs of next generation narrower track heads are very high. Higher TPI equates to more test revolutions which equals longer test times and less throughput for each test cell.

Test time - increased FCI/BPI and TPI mean increased test time. The rotational speeds can be increased to the limits of the head read-write rate and channel silicon limitations. If faster channels and heads could be developed, there are certain mechanical limitations, including narrow track width, track following capabilities (including spindle runout) and the strength of the substrate materials at high centripetal forces (hoop stresses), which will still be limiting factors on test time and throughput. Now show me the head that flies in a stable manner at 12,000 RPM! Which, is why most testing is still done at 5400 or 7200 RPM and low bit densities.

For consideration;

1). MR heads ? 5µm track width.

2). Conventional testing usually done at 5400 or 7200 RPM

3). A typical 95mm disk test extends from 16.5mm to 46mm (0.65" to 1.81")

4). Approximate optical test times for 100% surface coverage are:

66 secs @ 5400 rpm

50 secs @ 7200 rpm

35 secs @ 10,000 rpm

28 secs @ 12,500 rpm

Process control - As manufacturing processes become more refined, additional data is required to track and project manufacturing output. It is imperative that today's test and certification operations have statistical support. Skip track testing, ID predictive testing, wide track testing and audit testing are all being used to increase manufacturing throughput. ID and OD amplitude checks, overwrite, bit shift and pulse width modulation are all examples of design parameters that require process control monitoring which can be performed with audit testing.

All of these factors have forced the disk test and certify process into many compromises. Consider that a doubling of the TPI requires a doubling of the test capabilities, floor space and support. Changes in FCI/BPI require changes in head and channel electronics or proportional increases in the test capabilities.

A manufacturing facility used to be split 75% disk production (revenue) and 25% disk test (no value added). Very soon it will progress to 25% production and 75% test if one stays with current (established) technologies. Either the computer user accepts higher error rates and the drive manufacturer accepts higher reject rates, or the disk manufacturer tests more, or, we must find a new and faster test method.

Optical Testing

Optical testing, or more specifically, scanning the part to be tested with a small diameter laser beam at high RPM, offers several advantages:

Speed - High speed, wide bandpass laser systems can allow rotational speeds up to 15,000 RPM - about the same point that the modulus of hoop stresses of the aluminum comes into dynamic prominence. With a 5µm radius beam the total test time for a full disk, dual sided scan is under 12 seconds per surface. With a 2½ µm beam radius, defects with spatial size of 2 µm can easily be seen. A defect the size of the measuring beam can be readily measured to a vertical resolution of 0.01µ".

Speed - When the disk is scanned optically, a full surface image is created and stored in computer memory (RAM). The image can then be compared with/using multiple test criteria and thus eliminate the requirement for re-testing.

Speed - Without the mechanical interface of the head, downtime is greatly reduced. Calibration, re-certification, alignment and head load problems are all eliminated with the corresponding increase in up-time and throughput.

Speed - With the faster scan times, elimination of re-testing and decreased downtime, the increased throughput equals speed equals more production test capability in the same space with the same personnel.

Optical testing capabilities

Optical test "data gathering techniques" can be separated into two types; scanning and point data. Point data is used where data does not have to be continuous. This technique can be used to map runout, clamp and tooling distortions (Figure 6), microwaviness, flutter or resonance and, as an extension of the same principles, head flyability[3]. Scanning techniques are used when the features to be measured are small distortions, protrusions or inclusions in the presence of large scale distortions. This technique is used, for example, in defect scanning for pits and scratches, asperities and surface discoloration (Figure 7).

Three kinds of information can be gathered from the laser; fringe counting displacement data (height), Doppler shift velocity information and reflected energy. If the beam size is sufficiently small and the system bandpass sufficiently high, small disturbances can be measured on the surface of the test subject. Resolution becomes a function of beam diameter, measurement bandwidth, processing circuitry and data acquisition speed.

The measurement techniques for RVA , microwaviness, resonance, etc. are all understood and accepted . The reflectivity measurements are interesting and show features that may indicate contamination or process problems. This area awaits further research in a manufacturing environment. However, it is the study of small pits, scratches and asperities that offer interesting possibilities to reduce the test time and costs.

Optical Certification ™

We have no doubt that Optical Certification ™ is viable. Technically the task can be accomplished today and production tests have shown correlation in the >95% range (Figure 8a and 8b). The major barrier to implementation is not technical but psychological. After all, who in their right minds would believe that a ***light*** beam can find ***magnetic*** defects! Regardless of the fact that when you examine a disk surface in the failure analysis laboratory you start with a ***light*** microscope followed with AFM's, SEM's, and interferometers using filtered, monochromatic (red) light or ***lasers***. Regardless of the fact that you also ascribe a physical cause (a pit, a scratch, an asperity, missing coating or contamination) to where the magnetic defect is located. Wow, what a revelation! Just maybe, perhaps, full surface scans of the disk at high speed, with a laser beam, looking for the mechanical cause of the magnetic defect can be very cost effective and efficient. Just a THôT.

[3] Optical Glide, Optical Certification and Flyability are trademarks of THôT Technologies, Inc.

But, back to the original problem. The test requirement is growing at a much faster rate than the manufacturing process. How can we increase through-put, decrease costs and increase quality? Easy, GIGO, garbage-in, garbage-out. Therefore, don't put garbage in.

To date we have not seen a sputtering machine that generates pits and scratches. With a high correlation of defects at the magnetic certification stage to pits and scratches on the disk surface, it seems obvious to us that disks should be certified as "sputter ready" prior to sputter and the questionable disks separated out at this stage for either re-polish or reclaim. (Figure 9)

Pre-sputter testing

Scanning sputter ready parts has several advantages.

Fast.	45 second scans for the full disk with dual sided 2.5µm radius beam coverage
Accurate.	Vertical resolution to within 10Å.
Cost effective.	Save the cost of sputtering bad parts. Save the lubrication process capacity. Save the burnish, glide and certification time. Rework of rejected parts is simple (no stripping of the sputtered layers is necessary).

When could this technology be on-line?

Aside from the obvious answer, ***now***, a realistic time for correlation, equipment acquisition and, training could be;

1). Correlation to magnetic defects	6-12 months
2). Correlate the defects to the nickel polish stage	3-6 months
3). Order and qualify and install the equipment	3-4 months
4). Full automation on-line	3-6 months
Total time to bring on-line (serial approach)	15-28 months
Total time[4] to bring on-line (parallel approach)	6-12 months

[4] A word of explanation about this time line. We have given a "worst case" reckoning for full implementation of optical testing. Steps 1 to 4 can be approached in either serial or parallel fashion. One company has elected to skip step 1 but is adopting the serial approach while another has adopted a "pseudo parallel" approach.

Conclusion

The manufacturing difficulties experienced in the disk and drive industry today are much like finding a brick wall in the way of progress. We do, however, have choices. We can beat our heads against the bricks until we either demolish the wall or our head hurts (choose one). The alternative is that we can get smart and find a way to either climb over, dig under, or step sideways to get around the barrier.

The economics of disk testing has become one of the brick walls in the way of progress. Optical laser scanning techniques present a path around the barrier. Optical laser scanning offers high speed, high accuracy, with associated low operating costs. More importantly, because optical scanners are non-contact measurement techniques, they can not only be used at the most economic point in today's process, but are capable of adapting should the disk test methods and application points change in the future.

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