

Here's Looking At You

A Short Review of Current Optical Test Technology

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Optical testing has been around for almost fifty years but the last five years have seen an explosion in the use and application of the technology in the disk industry. As with any new technology, there are a lot of misconceptions and misunderstandings as the technology is implemented. Sometimes these misunderstandings can be costly either in choosing a wrong approach or in missing a cost effective solution. Not that the equipment manufacturers make the task any easier as each one uses nondescript terms and potentially misleading statements in their specification sheets.

And, it is not going to change soon. There is a movement within IDEMA to create a standard for optical testing. But every optical technology is lumped into one group; interferometry, Doppler vibrometry, scatterometry and elipseometry. We might as well toss in microscopy and include AFMs, SEMs and magnifying glasses. The confusion runs rampant. Decisions are made based on through-put without regard to resolution and resolutions are stated in very confusing terms. In many cases, defect detection levels are stated as a spherical measurement. In thirty years I do not recall ever seeing a spherical defect. Or, we are told that all asperities have low sloped edges and all contamination has sharp scatter angles. I guess we can redefine sputter arcs as contamination but this is getting a tad ridiculous. And, people keep mixing and interchanging the terms "detection" and "measurement". Detection levels are normally well below measurement capabilities and some instruments are incapable of measurement.

Lets back up and start at the basics. The first question is; what are you trying to measure? If we examine the spatial relationships of the surface features that we wish to inspect, we can express it as shown in Figure 1. The horizontal scale shows frequency increasing (decreasing defect size) to the right and the vertical scale shows increasing amplitude and quantity. Note that the vertical scale is amplified at a linear rate from 1 to 10X to help display the very small features. To perform a measurement we may need to remove the other features that are not of interest. In the global sense, we are not concerned about "surface finish" if we make a runout or "flutter" measurement because the surface finish has a very small value compared with the surface runout. But, in contrast, we need to remove the large values of runout, flutter and waviness and must still have the dynamic performance to measure defects and surface finish.

There are several methods that can be used to examine specific defect types while removing unwanted features. Some techniques cannot measure all of the features and are limited in their application. Scatterometry cannot be used to measure displacement and therefore is not used to measure runout or flutter. Interferometry provides an excellent measurement method for the measurement of low frequency "events". The interferometer can be used to make surface feature measurements as long as the total number of data points is kept relatively low. Interferometers have a

relatively slow data acquisition rate (due to $1/4$ plate focus acquisition time) and are normally used to measure low density runout scans or very limited, small area, defect scans. Vibrometers cannot measure from DC through a couple of cycles but are within their linear operating range above six (6) Hz. A vibrometer can only make dynamic measurements and requires that the disk be rotated at 360 rpm or more but, a vibrometer has a bandwidth of up to 1500 times that of an interferometer.

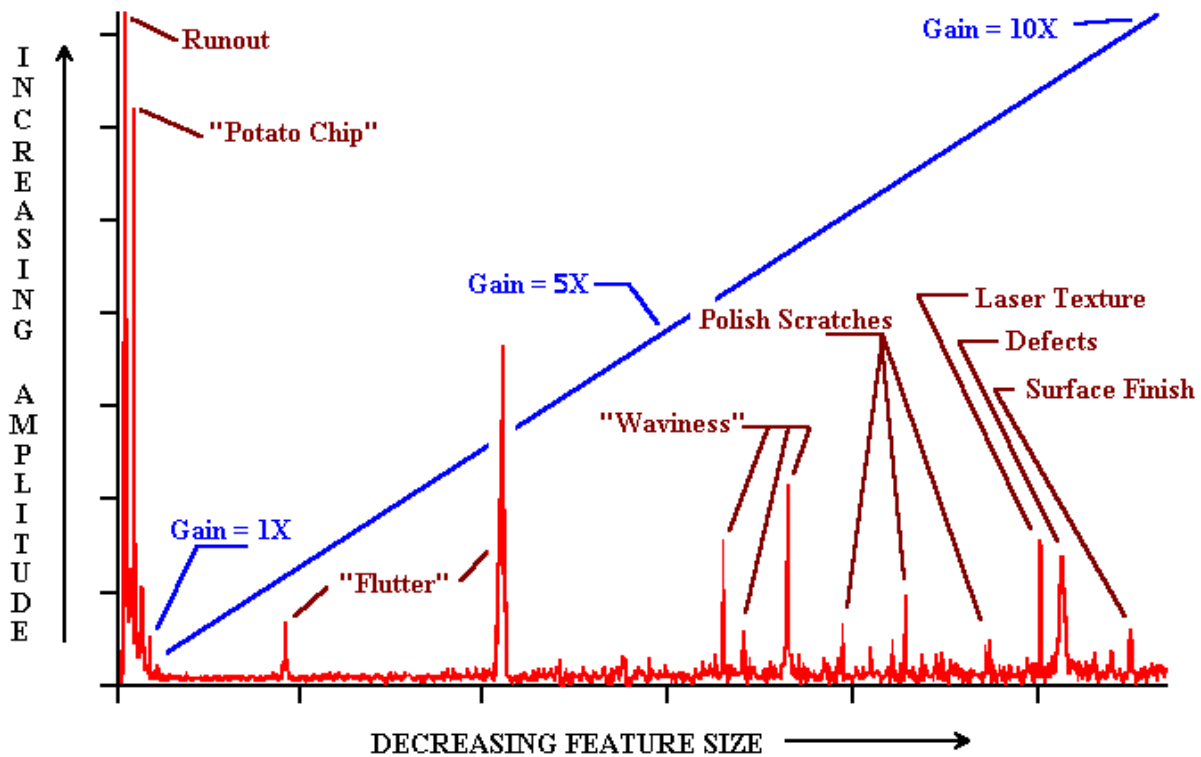


Figure 1

This plot shows an FFT for surface metrology of a 3.5" disk. The surface variations are separated by size (frequency) and "added" by amplitude and quantity. A linear gain is applied from one (1) to ten (10) X to allow examination of the very low amplitude, high frequency events.

Next, we need to examine the detection threshold. This varies with the technology applied to make the measurement or rather, the detection. Obviously, scatter techniques do not measure and, by the very nature of the technique, have difficulty in finding isolated, small defects at fast scan rates. One scatter type instrument advertises a test time of about 7 seconds for a 3.5" disk with a detection limit of 1000\AA (4μ "). To decrease detection limit down to 125\AA ($1/2\mu$ ") requires a 13X increase (over one and a half minutes) in test time. Most scatter type instruments are tested and calibrated using patterns or groups of spheres. The idealized application for a scatterometer is in measuring patterned surfaces and there are several, very good, commercial instruments designed specifically to perform surface finish measurements using very refined techniques and algorithms to compare the results to predetermined test values.

Ellipsometry is a very good thin film measurement technique but this optical testing method does not really apply to disk distortion or defect measurement. Ellipsometry is a very valuable tool in measuring magnetic and carbon layer thickness, lube dispersion, wear of thin film heads and constants (n and k) for flying height measurements. While an ellipsometer could be operated in "scatterometer" mode, there would be no particular advantage and the time to make the polarization rotation measurement would significantly add to the overall test time.

This leaves two methods of making disk surface measurements optically and now the operative term is measurement. The two methods are interferometry and vibrometry. Unfortunately, both methods must comply with the basic laws of physics and the optical limitations of the system. Interferometric resolutions for height measurements can be pushed to $\lambda/512$ (wavelength divided by 512) or slightly more than 12\AA . This is considered to be a very good resolution for an interferometer due to signal noise and system vibration limitations. Doppler vibrometry has a theoretical noise floor of 0.01\AA and a practical measurement resolution limitation of 1\AA . And, while interferometers have a maximum measurement limited by the overall quality of the system (typically limited by coherence length), even low quality systems have ranges of several inches. LDVs (Laser Doppler Vibrometers) are normally limited by the focal depth of the optics and this can vary from half an inch down to tens of microns.

While the "detection" signal levels for interferometers and vibrometers are very low (12\AA and 1\AA , respectively), these instruments are normally specified in terms of measurement accuracy for events at full beam size. Beam size (diameter) can be affected by many things and this area is, to an optics engineer, what a new box of Legos is to a five year old. Still, there are several laws of physics that we still have not been able to overturn and, as a rule of thumb, small beams have short working distances and limited focal depths. With rough surface finishes (read – last years disk production) the "defect detection" level for interferometers and laser vibrometers was down to 20% of the beam diameter. Current "super polish" surfaces are allowing detection down to 10% of the beam diameter.

Now that we have defined the basic operating envelopes for the various technologies, let's destroy another myth. Some instruments measure scratches. Wrong. No instrument on the market today measures scratches. If the instrument is capable of measurement, it measures (otherwise it "detects") asperities or pits. A contiguous series of pits is a scratch or a series of asperities is a ridge. Some manufacturers like to say that they detect scratches when what is really done is that the signals are processed through some pattern recognition software routine. This feature is important because once you realize that it is pattern recognition, there is no reason (other than development time and money) that the pattern recognition routines could not identify straight scratches, curves, circles, circumferential or radial defect patterns.

At this point we have defect height, surface spatial size detection, measurement definitions and understand that we can identify patterns of defects, let's go back to Figure 1 and look at the applications. We are going to eliminate ellipsometry as it should be considered a special case and the only method discussed that can measure the thickness of thin film.

Runout - Easily measured both statically and dynamically by interferometry and dynamically by laser vibrometry. Both instruments have the dynamic measurement range, resolution and bandwidth. Typical spatial resolution requirements for runout and flutter measurements are shown in Figure 2. It should be noted that some interferometers will be limited in the dynamic measurement due to low bandwidth.

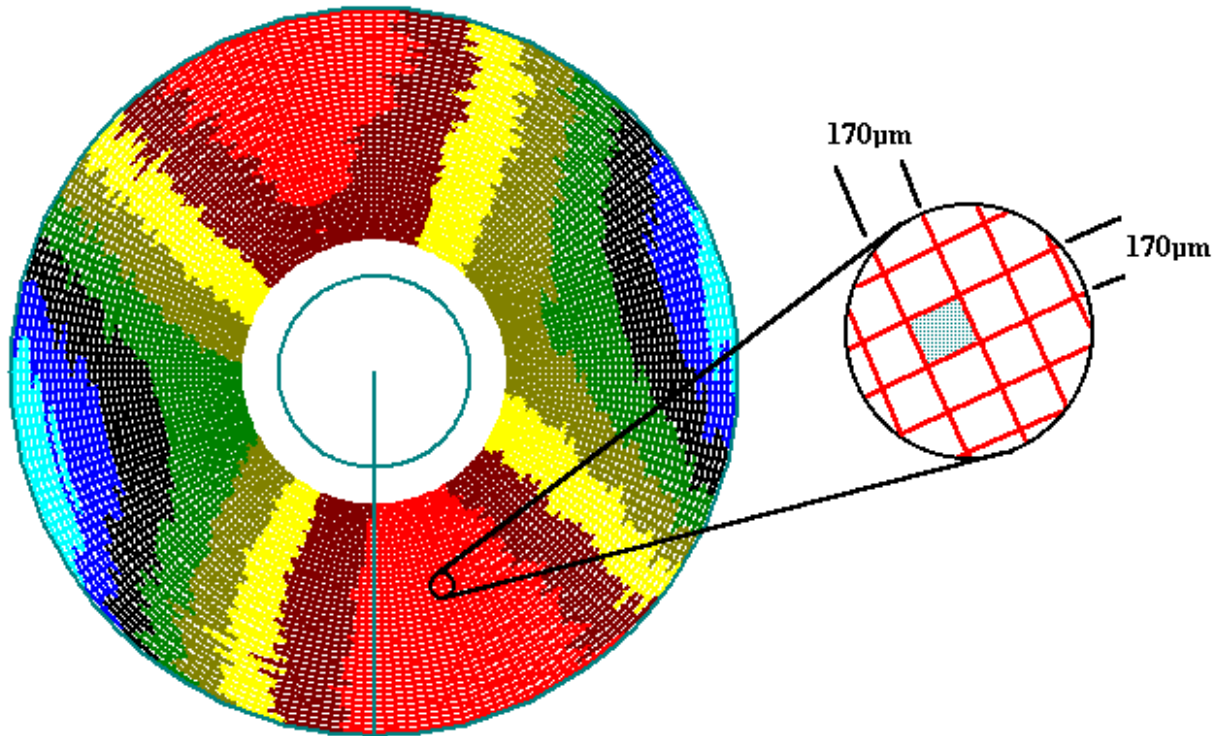


Figure 2

Runout measurement requirements are not stringent. Typically, data points are gathered at large spacing intervals or large beams (laser spot sizes) are used. Spacings or beam sizes in the area of 150 to 200 microns are normal. The disk above shows the typical "potato chip" shape (red = high, blue = low)

Flutter – (Material resonances) can be measured dynamically by laser vibrometry or interferometry. Since this feature (see Figure 3) can *only* be examined dynamically, at one data point per degree, 360 data points per revolution, some interferometers will be limited to testing at 3600 rpm maximum or they will lose resolution. Because of the very wide bandwidth of a laser vibrometer, this restriction does not apply and several thousand data-points can be gathered per revolution at speeds up to 20,000 rpm.

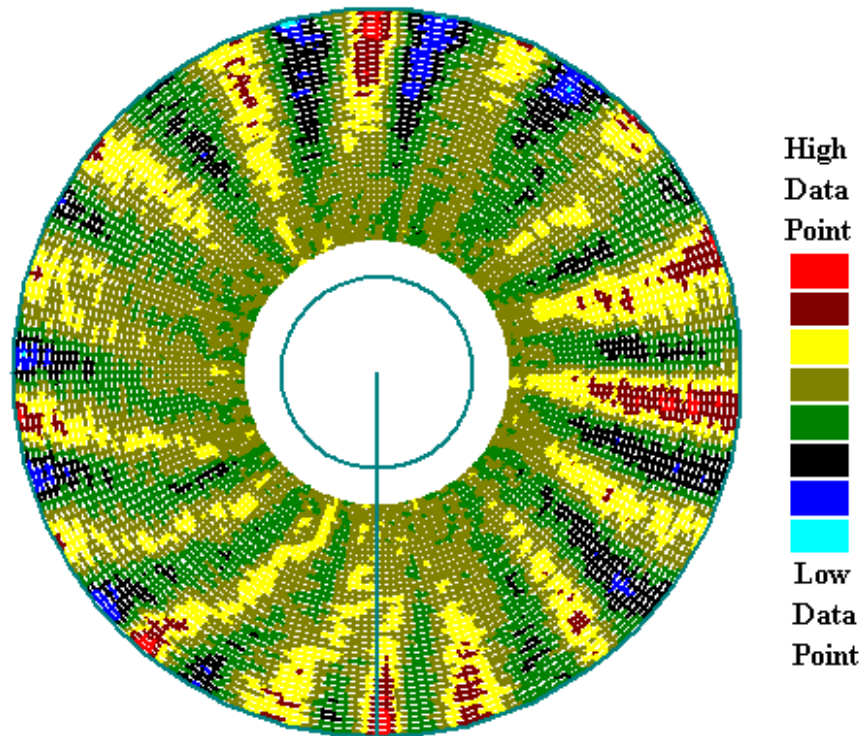


Figure 3

This figure shows the dynamic "flutter" of the disk viewed from a single data point (i.e. a laser beam or read/write head mounting point). The "spokes" are ridges and valleys that the head must fly over. The higher values at the disk OD are especially troublesome for ramp loaded heads.

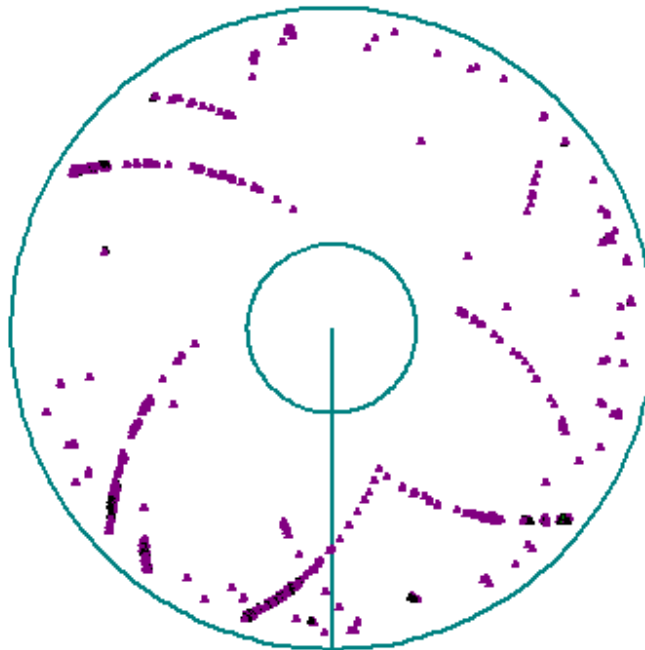


Figure 4

Wide, shallow polishing scratches can be easily viewed by use of a bandpass filter. These scratches cause magnetic defects due to spacing loss in drives with low flying heads.

Waviness – These features can be measured statically with an interferometer. Typically they have shorter wavelengths than the flutter features. This may limit the practical measurement area due to time constraints (bandwidth). At the same time, these features have too long a wavelength for a scatterometer to detect. With the very wide bandwidth of the laser vibrometer, it is possible to install a bandpass filter on the output of the vibrometer and select only the features desired for measurement. This technique is displayed in Figure 4.

Micro-waviness – Is normally considered to be short wavelength, surface finish features. Depending on the interferometer, measurements may have to be restricted to a small portion of the surface due to interferometer bandwidth limitations and reasonable test times. If the features are sufficiently small and the scatterometer beam is sufficiently large, it is possible that a scatter based instrument may be able to detect micro-waviness. The same type of filtering techniques used in measuring waviness can be applied to micro-waviness measurements made by a laser vibrometer as seen in Figure 5.

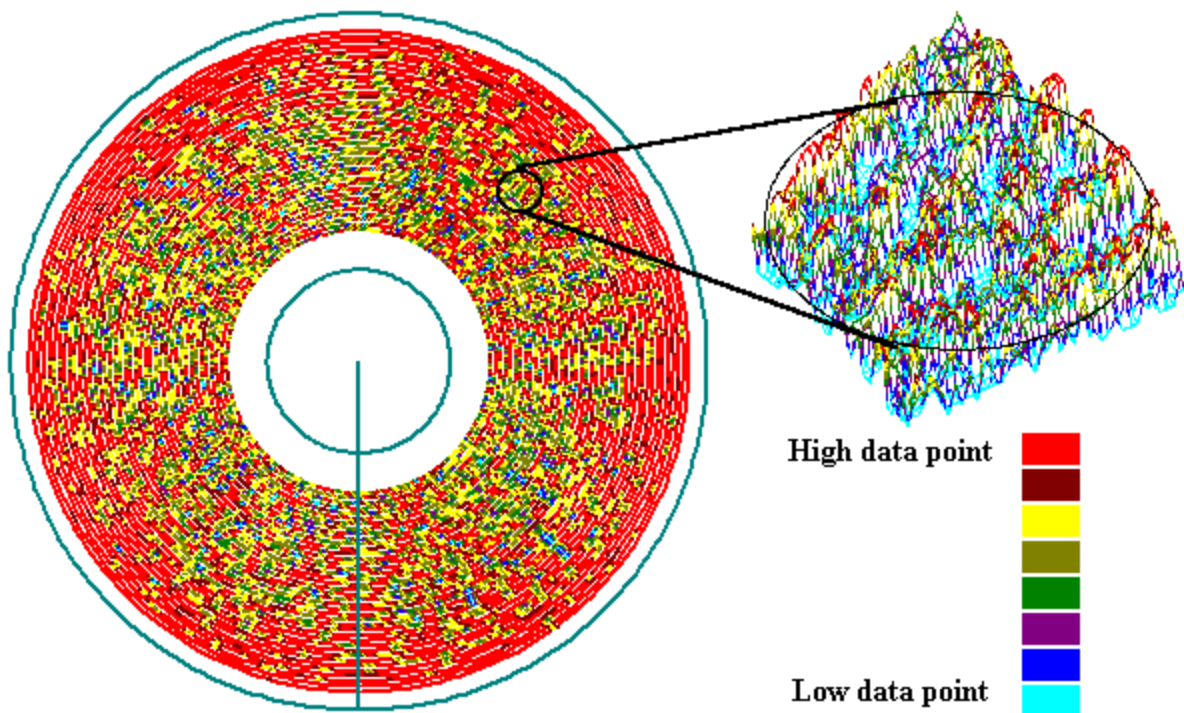


Figure 5

In this figure, runout, "flutter" and waviness are blocked by a high pass filter while defects and finish are blocked by a low pass filter. The remaining micro-waviness features are shown. These surface variations can cause head instability or data integrity problems.

Defects – While defects come in many forms, for the sake of this discussion, we will consider forms from 0.5 microns to several hundred microns wide and as shallow (or high) as 6Å of single, isolated defects. At the smallest defect level, the laser vibrometer is the only instrument capable of detection. As the size increases, the interferometer can also detect the defects. As we approach the one

micron size with a minimum height/depth of 12\AA , both instruments are capable of providing measurement capabilities. As we continue to increase the defect height to 100\AA we enter the slow scan detection capability for scatterometry and by 500\AA we can detect the defect with a high speed scatterometer. As we continue to expand the X-Y dimensions over 100 microns, we start to lose detail with a scatterometer.

This means that we now have two methods to rapidly scan for defects and provide accurate measurements. If we use a scatterometer for defect detection and couple it with an interferometer for measurement we can perform a surface scan, within the detection limitations of the scatterometer, and return to the defect location to measure the defect with the interferometer. The other method is to scan the surface with a laser vibrometer making direct measurements as the surface is scanned. All methods use a variation of the standard certifier polar display for this type of data (see Figure 6).

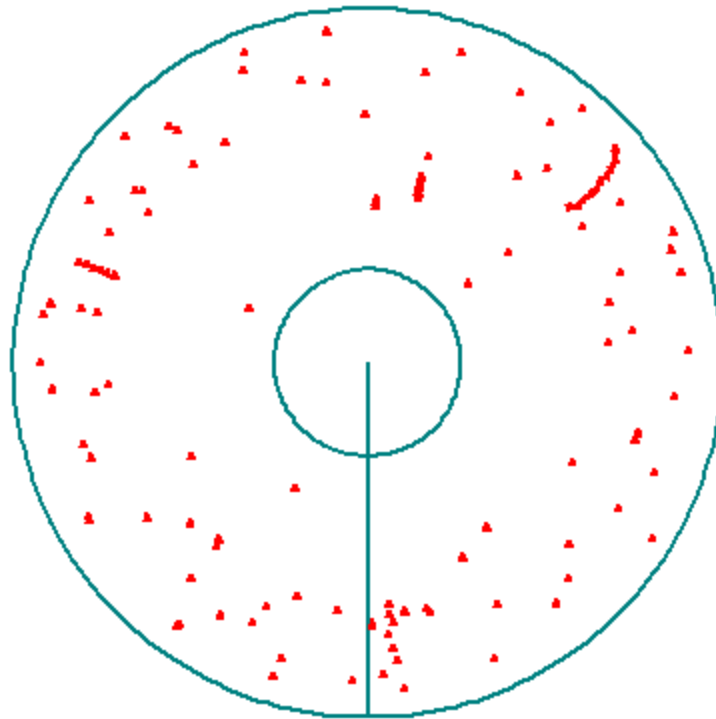


Figure 6

Defect map shows pits and asperities, ridges and scratches. Defect locations are indicated and various displays can be established for different types and/or severity of defect.

Surface finish – Of the optical methods discussed, this feature is most easily measured with a scatterometer. While interferometers and laser vibrometers can provide the same level of information, the interferometer would take many minutes to provide the data and the laser vibrometer would be faster but could not compare to the speed of the scatterometer. Unfortunately, the scatterometer would still not provide measurement data and could be "confused" by very smooth surfaces with several

defects under the beam and slightly rougher surfaces with no defects. Calibration in this mode of operation would require correlation to an AFM or SEM.

In summary, if you are going to look at optical testing, which you need to if you are going to be competitive, read those specifications with a jaded eye. The only thing more ambiguous than an optical tester specification is an analog IC specification or congressional testimony.

Acknowledgements:

Dr. Ian Freeman for the technical guidance.

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My mother for teaching me how to laugh.

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Mr. Eckerman is the president of THÔT Technologies and a 30+ year veteran of the disk drive industry. Prior to co-founding THÔT Technologies, he founded Lotus Technologies and has held positions managing test engineering and equipment functions dating back to Caelus Memories in the late 1960s with stops at Memorex, Univac, Xerox and several of the old test and process equipment companies. He claims to remember when \$10.00 per megabyte was a good price and programmers had respect for memory space.

NOTE:

This paper was originally submitted to Data Storage Magazine for publication. When the paper was edited by Data Storage Magazine, it was so heavily modified that major technical content was omitted. The paper was withdrawn and is being offered here because it is felt that the information will be useful to users of THÔT test equipment.