Magnetic Hard Disk Drive Form Factor Evolution

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***Abstract* - The trend towards smaller form factor in the magnetic disk storage industry is analyzed and discussed. Miniaturization is the result of small systems' storage requirements and advances in magnetic recording technology. This has led to the creation of a scaling methodology for determining disk drive sizes. We describe this and use it to project potential future form factors. Some limiting characteristics of disk drives in these form factors are examined.**

I. INTRODUCTION

The first magnetic hard disk drive product, 'RAMAC', introduced by IBM in 1956, stored 5 MB on fifty 24 inch disks [1]. It was developed to meet a requirement for a direct access storage device (DASD) for data processing. The technology applied was a magnetic coated disk on which data could be written, read, and erased repeatedly. Acceptable access times and data transfer rates allowed for maximum system performance at an affordable cost per MB stored. In the 36 years which have ensued, a major industry has grown in which current disk drive factory revenues are over $26 Billion [2]. This also generates an additional revenue for storage systems of about equal size. It is generally believed DASD product revenues may increase 100% within the current decade.

'High-End' DASD products currently provide rapid access to large quantities of data for large mainframe computer customer applications such as banks, airlines, insurance companies, etc. These large DASD-based storage systems possess orders of magnitude more storage capacity than the original RAMAC product. For example, the IBM Model 3390-3 'B' box stores 34 GBytes, and is about half the size of RAMAC. This particular system contains six separate head disk assembly units (HDA's), each with 5.68 GB on nine 10.8 inch disks.

The emergence of mini computing systems in the 1970's defined a need for less space used by the accompanying DASD storage devices. An eight inch disk and a rotary actuator were introduced at this time. Several drives could be packaged into desk height units, providing several hundred MB of storage. Often they were densely mounted in standard 19 inch rack formats, requiring powerful cooling systems.

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Each new form factor introduced has included smaller disk diameters and other reduced dimensions and parameters. The need for portable and hand held systems has highlighted weight, power dissipation, and ruggedness as well as size and cost. Technical advances in magnetic heads, disks, mechanics, and electronics are the key enablers for achieving the required design points. As an example, disk storage areal density is accelerating to compound growth rates above 30 percent per year (Fig. 1).

We explore here the trend to smaller disk drive form factors using a scaling methodology. Starting with the 5.25 inch form factor, the implications for future design trends are considered.

II. DASD FORM FACTOR SCALING METHODOLOGY

The evolution of disk drive form factors from 5.25 inch to smaller, more compact dimensions has been through submultiple reduction. This provides a pattern by which a progression of smaller sizes may be calculated. The parameters determined include disk diameter as well as height, width, and length of the HDA unit. Experience over the last several years is that this algorithm is common amongst many manufacturers who supply both captive and OEM markets, and this has facilitated industry standard form factors.

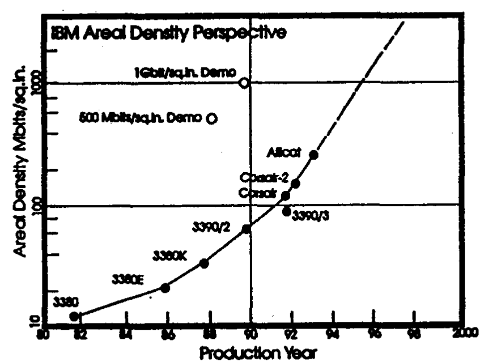

Fig.1 - Recent Progress in Areal Density versus Time for Disk Drive Technology. The points shown indicate IBM Products and Technology Demonstrations.

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The basic scaling algorithm is as follows:

a. Start from the standard 5.25 inch 'full height' form factor of 3.25 x 7.75 x 8.0 inches (H x W x L)

b. Reduce the disk area by 2. The next 'form factor' or disk diameter is thus $\sqrt{2}$ smaller.

c. The next width is 1/2 the LENGTH of the previous form factor.

d. The next length is the WIDTH of the previous form factor.

e. The next height is variable but can be 1/2 the HEIGHT of the previous form factor.

f. The dimensions are now determined. For successive form factors, iterate back to b. and repeat.

The net result of this scaling pattern as applied to the small drive form factors is shown in Fig. 2. With each iteration, the dimensions of the small drive form factors that have been built by the storage industry can be calculated.

With each iteration, the form factor volume is reduced by 4X. This is faster than would result by simply scaling everything by the disk diameter factor of $\sqrt{2}$. For example, if all dimension were scaled this way, the volume from the 5.25 to the 1 inch form factor would only be diminished by a factor of 5.25^3 (145) instead of 1024. Clearly, the effect of the more rapid height reduction reduces the HDA volume dramatically.

III. DASD DESIGN SCALING

The dimensions obtained from this scaling pattern can be used to estimate some limiting characteristics of DASD design at each size. To do this, we select an example that contains a) metrics common to many current disk drive designs, or b) limits based on power dissipation and air cooling. In this manner, insight may be obtained on where limits for each form factor may lie. The results predict some design points which may not be realized, in the same manner that form factors discussed above may all not find widespread use. The tendency in the industry has been that for each form factor, products are first introduced with modest capacity and performance, and are later improved.

Nominal Drive F/F	Disk Diameter	Width in./mm	Height in./mm	Length in./mm	Volume cu.in.	Volume Factor
5.25 in.	130 mm	5.75/ 146.05	3.25/ 82.6	8.0/ 203.2	149.5	1X
3.5	95	4.0/ 101.6	1.625/ 41.3	5.75/ 146.0	37.4	1/4X
2.5	65	2.87/ 73.0	0.81/ 20.5	4.0/ 101.6	9.3	1/16X
1.8	48	/54	/10	/73	2.4	1/64X
1.3	34	/38	/5	/50.8	0.6	1/256X
1.0	24	/27	/2.5	/36.5	0.15	1/1024X
0.7	17	/19	1.3	25.4	0.04	1/4096X

Fig. 2 - Hard Disk Drive Form Factors Based on Submultiples.

The scaling is done in the following manner:

a. ***Power*** - The DASD unit is taken as a rectangular parallelpiped with a single electronics card on the top surface. Five sides dissipate power from the spindle motor and actuator, about 20 mW/cm^2. The average actuator power is 25% of the spindle power. The power for the electronics card is taken as 60 mW/cm^2, corresponding to $\Delta T=12° C$ [3]. The arm electronics power within the HDA is small compared to the actuator and spindle motor.

b. ***Rotation Speed*** - From the available motor power, the spindle RPM is determined from the scaling of disk stack air shear power and disk diameter [4], for N, the number of disks as:

$$\text{Air Shear Power} = \propto d^{4.6}\,(\text{RPM})^{2.8}\,N$$

c. ***Areal Density, BPI, TPI*** - The areal density is scaled inversely with the disk area. The linear and track densities are found by assuming the outer to inner data band diameter is 2, a bit cell aspect ratio of 20, and 2800 tracks per surface.

d. ***Head-Media Clearance*** - This factor can be read simply from the plot of areal density versus clearance (Fig. 3). The graph illustrates the exponential relation of areal densities to spacing [5].

e. ***Data Rate*** - The disk diameter, RPM, and linear density, determine the maximum data rate of the disk drive (no zoning).

f. ***Actuator Performance*** - The seek time performance of the actuator is scaled with power, data band width and load inertia of the actuator assembly [6] as:

$$\text{Seek Time} = \propto \left[J_L \frac{\theta_L^2}{P_o} \right]^{1/3}$$

The values obtained from this scaling example are shown in Fig. 4. The scaling leads to a capacity per surface (non-zoned) of 124 MB. Of course, changing any of the above assumptions will affect the calculated values.

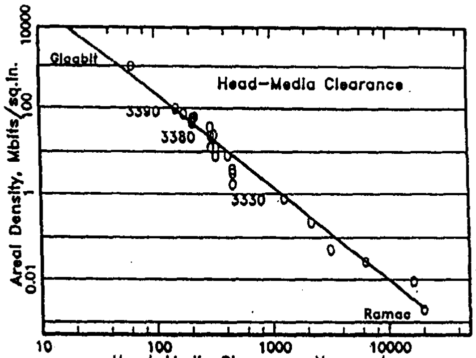

Fig. 3 - Areal Density versus Head Media Clearance. The points depicted indicated IBM Products, starting at RAMAC and include the Gb/in^2 technology demonstration.

IV. Discussion

It is interesting to examine the scaling results in Fig. 4 and compare to what currently exists in the storage industry [7]. For the 5.25 and 3.5 inch form factors, the results are close to the specifications for current products. For the 2.5 inch form factor, both areal density and power dissipation for existing 'product' designs are below the scaled values. This is because portable and hand held systems require low power and small size. Greater capacity and performance will be seen in these at a later date.

According to this scaling, areal densities of 1Gb/in^2 and above appear well-matched for the sub-1.8 inch form factors. In addition, very close head-disk clearances would have to be achieved. Recent discussions of 'near-contact or liquid film recording' for small file designs indicate this is emerging [8]. To have such high areal densities in larger form factors (>2.5 inch), much larger track and bit densities than those shown in Fig. 4 would be required.

Finally, it is interesting to notice that from the scaling assumptions presented here, performance (RPM, data rate, latency, and seek time) only increases modestly with smaller form factors. This is primarily due to the power dissipation constraints. Clearly, if higher temperature rise, better cooling, or both are allowed, then these factors may be increased to give much better performance. However, with the assumption of air cooling and modest temperature rise, performance will increase, but not dramatically. This may give some indication that other ways for higher performance suited to parallel architectures, such as DASD arrays [9], may receive more emphasis.

DASD SCALING FOR CAPACITY = 124MB/Surface

Form Factor* (in)	.7	1.0	1.25	1.8	2.5	3.5	5.25
Ht.	.05	.09	.19	.39	.81	1.63	3.25
Width	.75	1.06	1.45	2.1	2.8	4	5.75
Length	1	1.44	2	2.8	4	5.75	8
Total Power (W)	.41	.85	1.7	3.6	7.4	16	35
Electronics	.29	.59	1.1	2.4	4.5	8.9	17.8
Spindle	.09	.19	.41	.97	2.2	5.3	13.1
Actuator	.03	.07	.14	.32	.72	1.76	4.4
Areal Dens. (Gbit/in^2)	5.1	2.5	1.6	.77	.40	.205	.091
KTPI	16	11.2	9	6.2	4.5	3.2	2.1
KBPI	320	224	180	124	90	64	43
Clearance (nm)	20	30	45	75	100	130	200
RPM (x10^3)	14.3	11.0	10.3	8.1	6.7	5.4	4.1
Latency (msec)	2.1	2.7	2.9	3.7	4.5	5.5	7.3
Data Rate (MB/sec)	10.4	8.1	7.5	5.9	4.8	4	3
Seek Time (msec)	4.0	5.0	5.8	7.5	9.3	11.6	15.2
Assumptions:	OD/ID Ratio = 2 2800 Tracks/Surface Single Electronic Board		BPI/TPI = 20 Non-Zoned Air Cooled		RPM from Power ΔT ~12°C Max .06 w/cm^2 .02 w/cm^2		

Fig. 4 - Scaled DASD design limits for the Form Factors of Fig. 2 and the assumptions of Sec. III.

V. Conclusions

A scaling methodology for determining magnetic DASD form factors is discussed. In this way, the storage requirements of small computer systems are satisfied. The achievement of the smaller form factors depends critically on technical progress in all aspects of rigid disk magnetic recording technologies. Using the scaled form factors and metrics common to many DASD designs, limiting parameters are determined for each size. From this, high areal densities are well suited for smaller form factors. Performance improvement continues with smaller form factor, but dramatic advances may require drastically changed assumptions or more parallel storage systems architectures.

Acknowledgment

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