Flexible Disk Drives Overcome Adversity

past problems notwithstanding, system designers seem ready to forgive and forget ...almost

Having survived a feeble attack on one side from magnetic bubble memories, and a more formidable one on the other side from Winchesters, floppies have proven themselves far more durable and adaptable than most forecasters predicted. Despite past design problems, current advances in disk density and reliability ensure floppies' survival through the late-1980s, and perhaps beyond.

by Paul Snigier, *Editor*

Floppy disks are defined in terms of unformatted capacity in Kbytes or Mbytes, access time (ms), transfer rate (Kbits or Mbits/s or Mbps), error rate and cost/bit. Other factors to consider include backup, transportability and availability.

The primary consideration, storage capacity, currently ranges from 75-Kbytes to 3-Mbytes, and may soon reach the 5-Mbyte plateau. Some manufacturers are even hinting at 10 Mbyte floppy disk drives under development.

floppy fundamentals

Flexible disks, available in 8″ full size, 5.25″ minifloppies or 3.5″ microfloppies, are Mylar disks coated with a thin film of gamma iron oxide. Each disk is encased in a stiff polyvinyl chloride envelope that protects the disk from contaminants (such as dust and fingerprints) and provides rigidity. This square jacket, which does not cover the entire disk, is slotted to enable the R/W heads to contact the disk. The diskette's center hole enables the drive spindle to rotate the disk, while a notch on one side provides mechanical write-protect (preventing accidental erasure), and an index hole (providing timing information). In the past, floppy disks had a track density range of 35 to 77 concentric tracks; today, densities range from 48 to 96 tpi, with some going higher. Sectors (resembling wedge shaped portions) subdivide the diskette.

Hard-sectored diskettes, identifiable by timing information holes in front of each sector, hold more data than do soft-sectored diskettes. However, soft-sectored diskettes, identifiable by a single index hole, provide greater versatility in storing data, since sector locations are defined by controller and system software. Unfortunately, data determining soft-sector size must be stored within the sector. Although fixed formatting was more popular in the past, today's systems utilize soft-sectored diskette drives more frequently due to software flexibility.

Typically weighing about 13 lb. and measuring 5″W × 9″H × 14″D, the floppy disk drive has a die-cast frame as the primary structure to support components, such as the drive and stepper motors, index LED and detector, head load solenoid and other parts. R/W and control circuitry interpret and generate control signals that move the head to the selected track. A synchronous drive motor spins the spindle, usually at 360 RPM, by pulley and belt configuration. The registration hub, which is centered on the spindle face, properly centers the floppy. Moving with the cartridge guide, the clamp holds the diskette against the registration hub. In most drives a head position stepping motor turns a lead screw clockwise or counter clockwise in 15° increments to move the head. A platen (on the base casting) holds the diskette normal to the head. The diskette is loaded against the head with a load pad. This is actuated by the head-load solenoid.

double-headed dragons

The bad reputation of double-sided floppy disk drives is behind the industry; OEMs and end users, many of whom

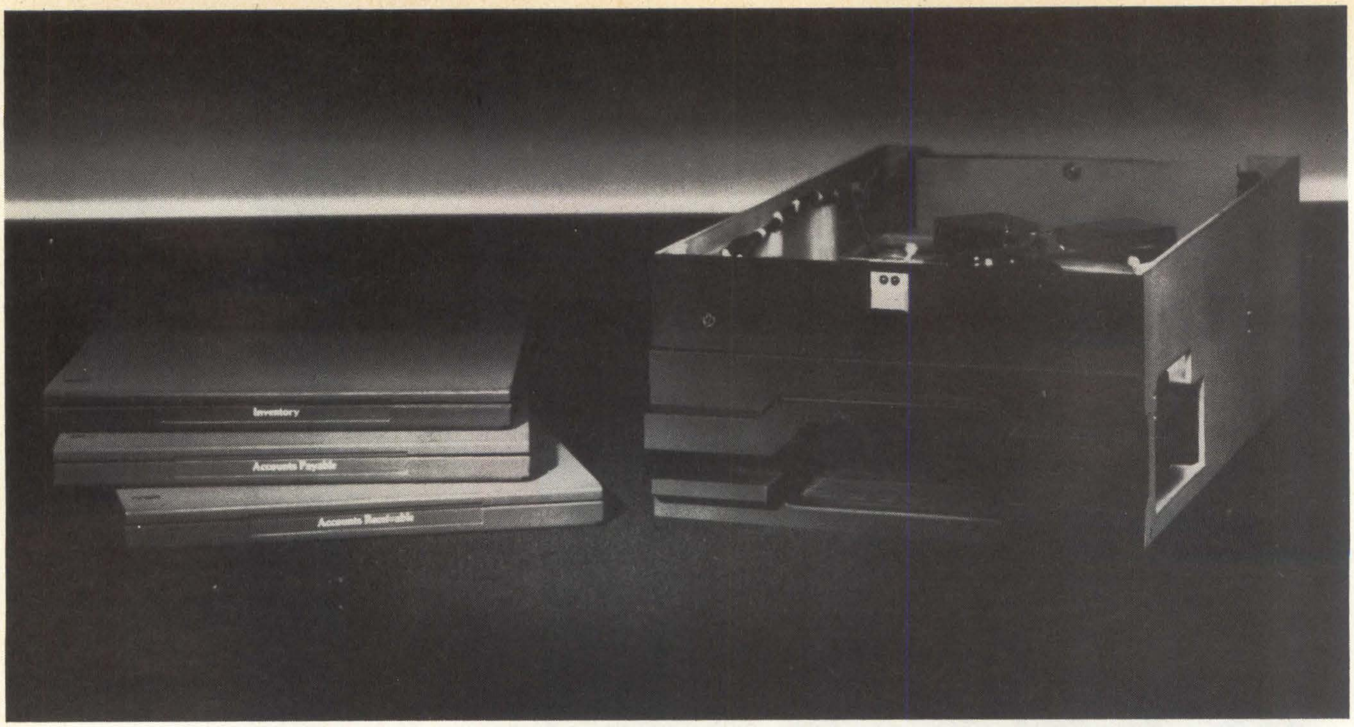

Figure 1: The ALPHA 10 combines Winchester technology with the low cost removability of flexible media. Iomega employs a system of media stabilization enabling the flexible media to fly at close proximity to the head, resulting in high density, non-contact recording.

were burned by the earlier double-sided drives, have overcome their fear of these floppies. Present double-sided floppy disk drives, whether using modified tri-compliant, bi-compliant or modified head assemblies, have now achieved the reliabilities that enable them to be used safely in systems without fear of damaging diskettes.

The double-sided floppy disk drive, first developed by IBM, was originally intended merely as an I/O or program-loading device. Both uses demanded only low duty rates. It was four years ago that Shugart Associates, recognizing the potential for the double-sided floppy as a small system memory device, introduced the first non-captive drive. Unfortunately for Shugart, their original design was a tri-compliant head assembly. This head assembly had three movable parts that included the diskette and two gimballed R/W heads. One head was attached to the lower carriage while the other was attached to a pivoting swing arm. It was a disaster. Excessive wear and head amplitude instability plagued diskettes, and Shugart failed to gear up for mass production: the design was too complex for less skilled workers. Requiring more assembly procedures and exactness, it added unnecessarily to the cost of the tri-compliant head assembly.

OEMs designed these early double-sided drives into their systems. After end users purchased them, monumental problems surfaced immediately. The double sided floppy disk drive had taken two giant steps backwards. Between lost sales, extra time taken by redesigning drives and the bad image and skepticism among purchasers, industry observers estimate that floppy disk drive development lost over a year.

Although some manufacturers perfected the tri-compliant head assembly and made modifications, Shugart Associates, not wanting to take any more chances, chose to totally redesign the head assembly, going with a bi-compliant design. This was due to problems in the tri-compliant head assembly. For example, head amplitude instability, caused by incorrect positioning of the two heads, resulted in weak or varying R/W signals. Since Mylar diskettes are not rigid, their amplitude undulates 0.13″ above and below the horizontal. As the diskette revolves, it also moves up and down, and the two heads become aligned and misaligned, creating a fading signal. On some drives, this was not a serious problem; on others, it was. It was not a situation that inspired confidence.

But this disk instability was just the first problem. The springing of the flexure arm permitted the sharp edge of the side 0 head to tear into the diskette, causing wear and surface pinch. This shortened both media and head life — not to mention the shortened tempers of OEMs and end users.

But diskette wear was occurring in these designs even when the drives were not in operation! Unfortunately, the movable side 0 head, remaining in place, added insult to injury by further scraping the disk when the heads were unloaded. IBM simply retracted both heads when the disk drive was not in operation, totally bypassing the problem. Other manufacturers weren't so lucky.

Although the original tri-compliant design could be manufactured with few defects, the complex assembly process had to be very carefully monitored with skilled workers and rigid controls. It also required greater assembly time, testing time and more complex equipment. Mass production, using semi-skilled workers and fewer assembly steps and less complex equipment, was out of the question.

confidence returns

Two years ago Shugart introduced its bi-compliant disk drive. It had two moving parts: the disk and a pivoted, gimballed upper-head (side 1). The lower head (side 0) was fixed. This gave the diskette stability, since a spring-loaded arm on the movable upper head pushed it down on the lower fixed head. This, combined with a contoured design with no sharp edges, succeeded in eliminating most diskette wear. The arm flexure did not take place, since the lower side 0 was held rigidly in place. As a side benefit, the bi-compliant design permitted easier measuring and controlling of the head penetration depth into the diskette, thus providing superior control. Furthermore, assembly steps were reduced from 19 to 10, permitting mass production. As a result, confidence has returned, and MTBFs are rising. One manufacturer, offering a 1.6-Mbyte floppy disk drive with an advanced contour head and air damper (to smooth and cushion ceramic head-to-diskette contact), guarantees a 15,000-hour MTBF for the entire drive.

Head assemblies for double-sided floppy disk drives that reduce head and disk wear and can be mounted in carriage/loading arm assemblies now are commonly available. Assemblies may include ferrite/ceramic single-track magnetic heads with R/W sections and tunnel erase sections. For example, one company offers a button-shaped assembly with a torsion spring that provides stiff controlled head support about the pitch axis and along the vertical axis, but allows flexible movement about the roll axis. The second head assembly, rectangular-shaped, has a gimball flexure to support the head, thus providing flexible movement along the vertical axis and about the pitch and roll axes. The disk bearing surfaces are finely polished to a maximum of 3μin. When installed in the carriage/loading arm assembly, these two head assemblies are on opposite diskette sides, facing each other. The larger button-shaped head assembly is mounted on side 0 of the disk. The rectangular-shaped head assembly is mounted on the loading arm. During operation, the diskette loads against the button-shaped head assembly, slightly deflecting the diskette along the vertical axis. When rotating, variations in disk flexure are compensated for by the torsion spring and the gimball supported heads. This keeps firm contact between head and disk surfaces, yet avoids high loading forces.

The rectangular head assembly measures 1.09″ in length and 0.500″ wide in overall dimensions. The head itself is much smaller. The button-shaped head, which contains the torsion spring, resembles a doorbell in appearance. It is 0.620″ in diameter and 0.285″ in height. The head, which is in the center, is approximately 0.20″ in diameter.

double-density disk drives

Single density disk drives use double frequency NRZI recording. This double frequency inserts a clock bit at the start of each bit cell, thus doubling the frequency of recorded bits. A 1 is encoded by a flux change; a 0, by an absence of a change. NRZI provides an advantage in that if an error occurs, it is limited to the error bit only and does not put following bits in error. In double density disk drives, if a data bit is present, a clock bit is not written at the start of a bit cell. This cuts bit cell size in half, doubling data space. Decreased bit cell size does have a price: encoding prior to writing and decoding when reading require more complicated circuitry. In addition, extra circuitry is needed to compensate for the higher tolerance needed due to the smaller bit cell tolerance. Encoder requires precompensation circuitry and the separator requires PLL.

hard- vs soft-sector

Hard-sectored diskettes contain tracks subdivided into a number of sectors. Sectors are pre-punched holes on the diskette at the same radius as the index hole. An index LED on one side of the diskette shines through the index hole to the index detector. Signals are sent to the control logic circuitry; these initiate format operations, generate ready signal outputted from the control logic circuitry, insure one revolution has been searched, and act as deselect storage device signals after a given number of revolutions are completed. Once the index is separated from the sector holes by the control circuitry, it sequentially counts the sectors from the index. With the improved format controller ICs available and the flexibility offered by soft sector (despite overhead memory storage requirements), the hard sector format is disappearing.

Like hard-sector, soft-sector is physical allocation of diskette space. Each track is divided into records. In selecting a track format, consider these factors: rotational tolerance, minimum inside track length, instantaneous revolution tolerance, physical index variation, write oscillator tolerance, read preamplify recovery time, maximum bytes from end of erase core and R/W gap, nominal byte time, nominal rotational time and nominal bytes/track.

data densities rise

Data densities will continue to increase; floppy disk drives hardly represent mature technology. Costs, which continue to decline, presently are in the \$150 - \$320/Mbyte range.

To increase track densities beyond 48 tpi for 8″ floppies and 48 or 96 tpi for 5.25″ floppies requires improved Mylar base material and new track positioning techniques. Mylar substrate, 3 mils thick, encoded with a 125μin iron-oxide

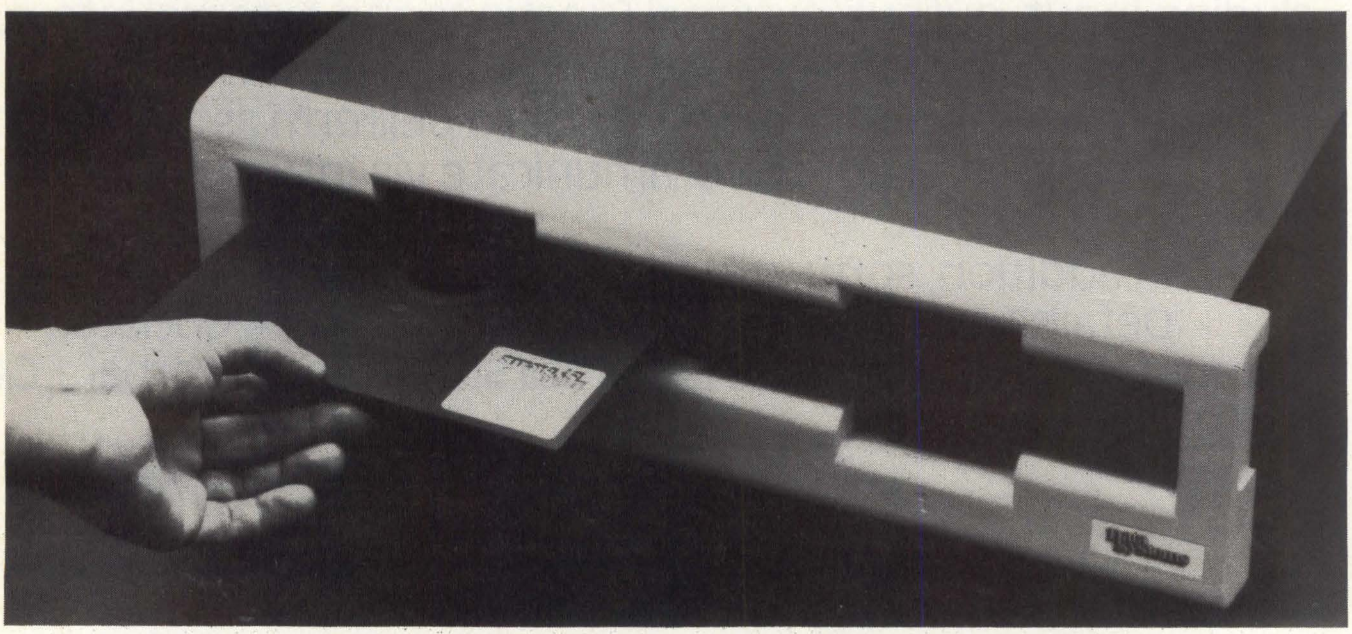

Figure 2: This floppy disk storage system transfers data files between DEC and IBM computer systems. The DSD 480 stores 1 Mbyte per 8″ diskette, for 2 Mbytes formatted on-line storage.

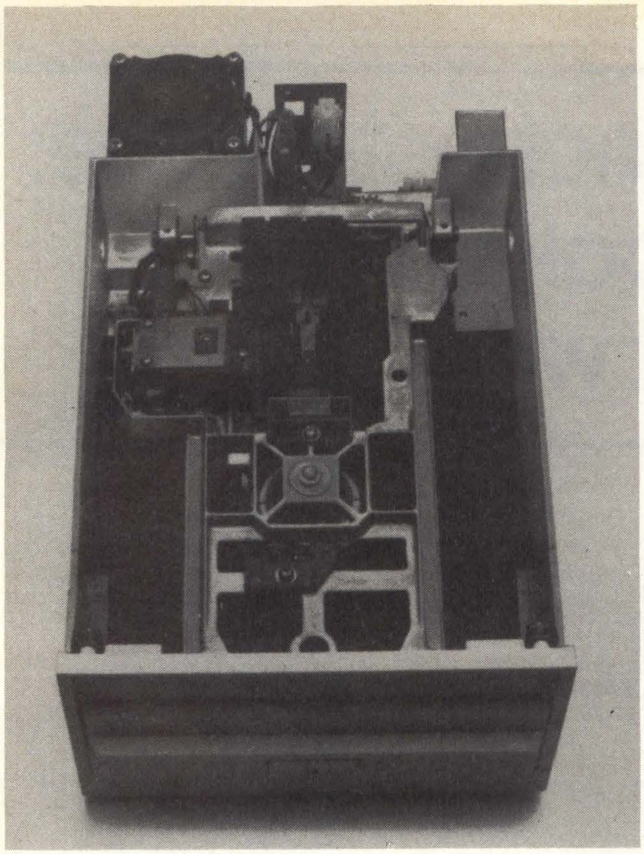

Figure 3: Model M2894-63 features an all-ferrite MnZn Gimbal-mounted head assembly which, according to Mitsubishi, reduces wear and assures track accuracy.

coating, is too easily affected by temperature and humidity changes. Although compensation schemes are used, changes in the substrate are non-uniform (nonisotropic and hygroscopic).

With improved recording media, and improved track-following schemes, track densities of 300 tpi are possible by 1983.

These improvements in floppy disk drive densities and capacity will have several effects on the technology and industry. Magnetic bubble memories, failing to decrease in cost/bit as predicted two years ago, may never recover to be cost competitive with the low end of the flexible disk drive market. On the opposite end, flexible disk drives will move up into the market presently dominated by low-end Winchesters, which in turn have eroded the 8" Winchester market. Floppy disk storage in the 2.5-Mbyte range is presently available.

half-size 5.25" diskette drives

Able to hold twice the memory of a Shugart drive without requiring extra space or power, a half-size 5.25" floppy disk drive is now available from ALPS Electric (NY). It typifies a trend. Only 1.69" high, the FDM 2000 is thin enough so that two such units can fit into the slot space of one 125-K or 250-Kbyte SA 400 drives. Said to be under development by other manufacturers, these half-size drives will find applications in replacing present standard-size units. The drive uses a belt and spindle actuator and has a ceramic head positioned with a metal band. Also, 2.1" high, 5.25" drives exist and are available from other manufacturers, who claim that these units are more marketable since existing systems have slots to accommodate them. At any rate, the FDM 2000 (available in 125-Kbyte and 250-Kbyte versions) marks the beginning of a new trend. Drives are priced at $300 in unit quantities and $150 or less in 1-k quantities, but will drop.

the drive to increased capacity

Embedded servos sharing track locations with data are increasing tpi. As mentioned earlier, flexible diskettes are anisotropic, meaning that they change nonuniformly with temperature, age and humidity. Unfortunately, this means that the R/W head must follow a nonradial, often elliptical track. Typically, a different surface is dedicated for writing servo information. New approaches to solving the problem of anisotropicity involve placing servo information on the same track as recorded data. This approach will not only alleviate head-to-track misregistration, but will enable the floppy disk drive to achieve much higher track and areal densities than could be predicted just one year ago.

Iomega's Alpha 10 and PerSci's 899, incorporating track-following servos for the first time, boast extremely high densities. Servo and data sharing of the same track locations will push floppy capacity even higher and rapidly encroach upon low end Winchester drives. It also seals the long term fate of bubble memory.

Sampled-data servo systems are susceptible to signal drop-out occurring in servo and data signals. Since the servo system cannot receive servo information between servo sectors, any media or other interrupt defect or interruption in a servo signal for 100 μs will compromise servo system integrity. Present approaches to circumvent this serious problem involve buried servos on standard diskettes.

In the buried servo diskette, R/W data is on the top 1.5 μm, while the deeper depths provide servo data. In this manner, servo data does not interfere with R/W data or suffer from hygroscopic (humidity) effects.

To penetrate into the magnetic media requires a long-gap head to record the low frequency servo signals. A higher frequency and higher bandwidth servo will R/W higher densities.

Unfortunately, many existing servo systems use pulse modulation. Since a pulse is made up of a dc component, a fundamental, plus many harmonics, this can create problems: the harmonics can interfere with data, which, being composed of fundamentals and harmonics, can create interference. Newer servo devices use a single frequency, preventing the problem of interference and also minimizing filter complexity.

Voice-coil actuators are now being used on floppy disk drives to achieve higher track densities and maintain positional accuracy. PerSci's 899 increases track density from 96 to 150 tpi. Industry spokesmen expect a 300 tpi by 1983.

If these higher track densities are achieved, improved ECC will be needed in the head data sent to disk file or in the controller circuitry.

the microfloppy

Sony's 3.5" diskette, introduced last December as part of their new Series 35 WP system, offers some truly impressive specs; in addition to a small 4" X 5.1" X 2", 1.7-lb. package, its 437.5-Kbyte capacity (single-sided, double-density format) stores 230 pages of text. Other specs include a track density of 135 tpi, as compared with 48 tpi for standard floppies and 96 or 48 tpi for 5.25" drives. Due to the lessened influence of hygroscopic or other anisotropic effects for smaller diskettes, the track densities obtainable with smaller diameter diskettes are naturally greater.

The 3.5" drive offers volume and weight reductions that are 27% and 56%, respectively, of the 5.25" diskette drives.