Low cost magneto-optic disk byte error rate testing system

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ABSTRACT

A low cost byte error rate testing system for 90mm magneto-optic (MO) disks had been developed. In order to achieve low cost and to perform the testing under realistic operating conditions, commercial magneto-optic disk drives were used instead of high-priced, specialized disk tester. An IBM compatible 486-DX33 PC was used as the controller. The design goal of the testing system is to find the best cost/performance system configuration. A model was developed to predict the testing system performance based on the DMA data rate, SCSI bus data rate, MO drive data rate, access time, processor speed, and the number of sectors, N, involved in each read/write operation. Three configurations were studied: (1) only one MO drive; (2) two MO drives are connected to PC through separate SCSI host adaptor; and (3) two MO drives connected to PC through one SCSI host adaptor in daisy-chain manner. The testing time of a disk varies from 40 min. to 24 min. when N is varied from 20 to 109. These testing times include the 10 min. of formatting time which is independent of N. The average access time of the MO disk was found to depend on the number of sectors involved in each read/write operation. Also, the measured access time is always lower than the specified 40 msec. These two phenomena can be explained by the smaller distance that the optical head needed to travel during the byte error rate testing. Based on the measured access time, a refined model was used to predict the optimal cost/performance configuration. A system with 6 or 7 MO disk drives connected to a PC was found to have the best cost/performance ratio.

1. INTRODUCTION

For the erasable magneto-optic disk manufacturing, it is imperative to test the quality of each disk. To judge the quality of an MO disk, the most commonly used method is to measure the raw byte error rate, i.e., write a certain data pattern to the entire disk, then read data back from the disk and check byte by byte whether there are mistakes in the read-back data. Usually, MO disk drives are connected to the personal computer (PC) through a SCSI[1] host adaptor card. All SCSI host adaptor cards and MO disk drives have Error-Correction-Code (ECC) capability. Thus, it is imperative that the byte error testing must be performed with all the ECC capability disabled in order to get the true byte error rate information of the disk. Due to the much larger data storage capacity on each MO disk (128 Mbyte or more) compared with that of a floppy disk (1.44 Mbyte), the testing time also becomes much longer. The typical testing time of a floppy disk is about 2 minutes, but that of a MO disk can be tens of minutes. This longer testing time can be a potential headache in production, e.g., if the testing time of a MO disk is 40 minutes, then each MO disk drive can only test 36 disks in a day. For a factory producing 5000 disk per day, then at least 139 MO disk drives are required to test these disks. If the testing time is reduced to 20 minutes, then the number of MO disk drive can be reduced to 70. Thus, reducing testing time reduces the cost of testing equipment and increases system reliability because less equipment were used. Since the MO disk drive must be controlled by a computer, it is also worth while to reduce the number of computers needed. For example, if each computer controls two MO drive instead of one, then the number of computer needed can be reduced by half. However, as the computer control more and more MO drives, the testing time of each disk may increase because all the MO drives may not work in parallel completely. Thus, there is an optimal configuration in terms of hardware cost of system performance.

Our goal is to develop a low cost, yet high accuracy and high performance byte error rate tester for the MO disks. We chose to use commercially available MO disk drives in our testing system to meet our low cost and high accuracy goals. It is obvious that a commercial disk drive is much cheaper than a specialized disk tester, but why higher accuracy?

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The point is that we want to measure the byte error rate of the disk under realistic working condition, i.e., even though the quality of the spindle motor, the accuracy of the laser intensity and head tracking of a commercial disk drive are not as good as those of a specialized disk tester, but these are the real operating conditions of a MO disk! Thus, we can obtain a more realistic measurement result using a low-cost commercial MO disk drive. A 486DX-33 PC was used to control the MO drives for its low cost. The efforts were spent in finding a system configuration and developing a test program that optimize the system performance.

2. SYSTEM SPECIFICATIONS

Since the system performance depends on the specifications of the components used, we will discuss briefly the specifications of MO disk, SCSI commands, MO disk drive, and the PC used.

2.1 MO disk specifications

According to ISO format mode 3 for 128Mbyte, 90mm MO disks, the data zone of a 90mm MO disk is formatted into 10000 concentric tracks, with tracks numbered from 0 to 9999. Each track contains 25 sectors. Each sector contains 600 bytes, of which 512 bytes are data bytes, and the rest of 88 bytes are the cyclic redundancy check (CRC) error correction code bytes. In a normal write operation, 512 bytes of data are sent by the computer to the MO disk drive. The MO drive generates 88 ECC bytes, and writes these 600 bytes into a MO disk sector. In a normal read operation, the MO drive reads 600 byte from a sector, but only sends the ECC corrected 512 data bytes to the computer. However, in doing byte error rate testing, 600 bytes of data must be transferred between computer and MO drive for each read and write operations. The format of a 128Mbyte, 90mm MO disk is shown in Fig. 1. Tracks 0 to 2 and tracks 9997 to 9999 are called Defect Management Areas, users are not allowed to write into these 6 tracks. These tracks contain four copies of Disk Definition Sectors (DDS), which record the starting sector addresses of the Primary Defect List (PDL) and Secondary Defect List (SDL). PDL and SDL contain a list of the addresses of bad sectors. The 9994 user-accessable tracks can be divided into arbitrary number of bands, whose function is similar to partitioning a hard disk into several logical disks. For our testing system, we always format the MO disk into a single band.

2.2 SCSI commands introduction

The standard computer interface of the MO disk drive is the SCSI bus interface. Thus, SCSI commands were used to in our testing program to control the operation of the MO drive. Only four SCSI commands were used: Mode Select, Format Unit, Read Long, and Write Long.

Mode Select command specifies how many bands should be formatted on the data zone of the MO disk. As shown in Fig. 1, a MO disk can be divided into n bands. In our case, we always set n to 1, so that the testing program can detect the byte error rate from tracks 3 to 9996.

Format Unit command simple formats the MO disk according to the mode set by the Mode Select command. A MO disk must be formatted before any read or write command can be issued.

Write Long and Read Long commands write and read data from the specified sectors, respectively. The starting sector number and number of sectors to be read or write are specified within the command. A Read Long command causes the MO drive to read 600 bytes from each disk sector and send these 600 bytes back to the computer without doing any ECC checking. In comparison, the MO drive will perform the ECC check and returns only 512 bytes back to the computer when responding to a normal Read command. Similarly, to perform a Write Long command, the computer must supply 600 bytes of data for each sector to be written. For a normal Write command, computer only supply 512 byte of data per sector, the rest of 88 bytes are generated by the ECC circuits on the MO drive. As mentioned in Sec. 2.1, the ECC function must be disable in our system, thus Write Long and Read Long must be used to test the true byte error rate.

2.3 PC, SCSI controller card, and MO drive specifications

The PC used is a 486DX-33 model whose DMA (Direct Memory Access) data transfer rate is 6.7 Mbyte/sec. The SCSI host adaptor card used is Adaptech AHA-1542CF. The SCSI bus data transfer rate in asynchronous mode is 2 Mbyte/sec. The MO disk used is SONY RMO-S350, with average seek time of 40 msec, 3000 rpm disk rotation speed, and 625 Kbyte/sec data transfer rate.

3. SYSTEM PERFORMANCE ANALYSIS

3.1 Timing model for a single MO drive configuration

We first consider the simplest case: only one MO drive is attached to the computer. The timing of the operations after the CPU issues a Write Long command to write N sectors of data to the MO disk is shown in Fig. 2. The following five operations occurs in sequence.

(i) 600 x N bytes of data are sent from main memory to the buffer memory on the SCSI host adaptor card through DMA operation. Since the DAM data transfer rate is 6.7 Mbyte/sec, the time it takes for this transfer, T_{DMA}, is

$$T_{DMA} = 600\ N \div\ 6.7\ \text{Mbyte/sec} = 0.09N\ \text{msec} \quad (1)$$

(ii) SCSI host adaptor card sends 600xN bytes of data to the buffer memory in the MO drive through SCSI bus. Since the SCSI data transfer rate is 2 Mbyte/sec, the time it takes for this transfer, T_{SCSI}, is

$$T_{SCSI} = 600\ N \div\ 2\ \text{Mbyte/sec} = 0.3N\ \text{msec} \quad (2)$$

(iii) To write data on to a sector on the MO disk, the optical Read/Write head of the MO drive must be positioned at the desired sector. The time for the head to move from the current position to the desired sector position is called seek time. This seek time can be divided into two parts. First, if the desired sector is not in the current track, then the head will need to travel radially to the desired track. Note that the optical head can only move in the radial direction along the disk. This time is called track seek time, $T_{seek\text{-}track}$. Obviously, this seek time is dependent on the head traveling distance. When the desired sector is on the current track, this seek time is 0. The maximum seek time occurs when the head needs to travel 9994 tracks. Once the head is positioned on the right track, there is another seek time called sector seek time, $T_{seek\text{-}sector}$, i.e., the head must wait for the desired sector to rotate under the head before the writing operation can commence. This seek time again is not a constant. If the desired sector is right under the head when the head moves into that track, then this seek time is 0. The maximum seek time occurs when the desired sector has just passed the optical head, it must wait for one full disk revolution time to do the write operation. With 3000 rpm rotation speed, this seek time can vary from 0 to 20 msec. The SONY RMO-S350 specifies an average seek time of 40 msec, this value is typically measured with head traveling half of the maximum distance and includes the sector seek time. Thus, the head seek time, T_{seek}, is

$$T_{seek} = 40\ \text{msec} \quad (3)$$

It appears that the head seek time is independent of the number of sector to be written. However, as we will discuss later, the number of sector written in each Write Long command affects the seek time in a very complicated manner.

(iv) After the head is properly positioned, the data on the desired sectors must be erased first. Since, the disk revolution time is 20 msec and each track has 25 sectors, the time to erase a sector is 0.8 msec. Thus, the time to erase N sectors, T_{erase}, is

$$T_{erase} = 0.8N\ \text{msec} \quad (4)$$

(v) After the data on the disk is erased, the new data can be written. The write time, T_{write}, is similar to the erase time, and is given by

$$T_{write} = 0.8N\ \text{msec} \quad (5)$$

Thus, the time required to do a Write Long N sectors command, $T_{write\text{-}N}$, is

$$T_{write\text{-}N} = T_{DMA} + T_{SCSI} + T_{seek} + T_{erase} + T_{write}$$
$$= 0.09N + 0.3N + 40 + 0.8N + 0.8N \text{ msec} = (1.99N + 40) \text{ msec} \quad (6)$$

The timing of the operations after the CPU issues a Read Long command to read N sectors of data from the MO disk is shown in Fig. 3. First, there is a head seek time, given by Eq.(3), to position the head to the desired track. Then, there is a read time, T_{read}, which is similar to the erase time, and is given by

$$T_{read} = 0.8N \text{ msec} \quad (7)$$

Then, there is a SCSI bus transfer time, given by Eq.(2), to transfer the data from MO drive to the SCSI host adaptor, and a DMA transfer time, given by Eq.(1), to transfer the data from SCSI host adaptor to the main memory. Once the data is stored in the main memory, the CPU performs the error checking. With a 33MHz CPU clock rate, the time to compare one byte of data is 0.42 µs. Thus, the time for CPU to perform error checking on N sector of data, T_{CPU}, is

$$T_{CPU} = 600 \text{ N x } 0.42 \text{ µs} = 0.25N \text{ msec} \quad (8)$$

Thus, the time required to do a Read Long N sectors command, $T_{read\text{-}N}$, is

$$T_{read\text{-}N} = T_{seek} + T_{read} + T_{SCSI} + T_{DMA} + T_{CPU}$$
$$= 40 + 0.8N + 0.3N + 0.09N + 0.25N \text{ msec} =(1.44N + 40) \text{ msec} \quad (9)$$

To do error checking on N sectors of data on the MO disk requires doing a Write Long N sector command and a Read Long N sector command. Thus, from Eqs. (6) and (9), the time required, $T_{N\text{-}sector}$, is

$$T_{N\text{-}sector} = T_{write\text{-}N} + T_{read\text{-}N} = (3.43N + 80) \text{ msec} \quad (10)$$

To check the whole disk, i.e., 9994x25 sectors, the total time, T_{total} is

$$T_{total} = T_{format} + T_{N\text{-}sector} \text{ x } 9994 \text{ x } 25 \div N = 603 + 857 + (19988 \div N) \text{ sec}, \quad (11)$$

where T_{format} is the time required to format a disk, and is 603 seconds for SONY RMO-S350. It can be seen from Eq.(11) that the total testing time consists of a constant term and another term which is inversely proportional to the number of sectors involved in each Write Long or Read Long command. With N=1, testing time is 357 minutes or close to 6 hours! With N=20, the testing time is reduced to 2460 seconds or 41 minutes, a factor of 8 decrease. Thus, to reduce the testing time, a large N value should be used. However, the value of N is limited by the DMA constrain on the PC, which specifies a maximum of 64 Kbyte per DMA transfer. Thus, the maximum value for N is 109. With N=109, the testing time is reduced to 1643 seconds or 27 minutes.

3.2 Timing model for multiple MO drives configuration

From the analysis in the last paragraph, it is observed that the CPU and SCSI host adaptor card are idle most of the time during testing. Thus, it is possible to add more MO drives to a computer without affecting the testing of each disk. From the point of lowering the total cost of the testing system, one would connect as many MO drives as possible to a computer before the testing time per disk begin to degrade. From Eqs.(6), (9) and (11), the testing time involving MO drive, T_{MO}, is

$$T_{MO} = T_{format} + (T_{seek} + T_{erase} + T_{write} + T_{seek} + T_{read}) \text{ x } 9994 \text{ x } 25 \div N$$
$$= 603 \text{ sec} + (40 + 0.8N + 0.8N + 40 + 0.8N) \text{ x } 9994 \text{ x } 25 \div N \text{ msec}$$
$$= 603 \text{ sec} + 600 \text{ sec} + (19988 \div N) \text{ sec} \quad (12)$$

Comparing Eq.(12) to Eq.(11), the testing time not involving MO drive, $T_{computer}$, is a constant 257 seconds. When using the optimal N value of 109, T_{MO} = 1386 sec. Thus, when connecting multiple MO drives to a computer and does not want to degrade the testing time per disk, the best one can do is to hide the $T_{computer}$ times of the additional MO drives under the T_{MO} time. From the ratio of T_{MO} and $T_{computer}$, 5.4 additional MO drives can be added. Thus, theoretically, the optimal system configuration is connecting 6 to 7 MO drives to a computer.

4. EXPERIMENTAL RESULTS

Three system configurations were tested and the results were given in the following paragraphs.

4.1 One MO drive connected to a computer

The testing times per disk for various N values (the number of sectors involved in a read or write command) were shown in Fig. 4. The curve with triangles is the theoretical curve based on Eq. (11), and the lower curve is the measured data. Due to the long testing time when N is small, we did not test the cases with N<20. For N=20 to 90, the measurement was done with N incremented by 5. For N=90 to 109, N was incremented by 1 to get more detailed information. It can be seen from Fig. 4 that the measured data has the same trend as the theoretical curve, but the measured data are always lower than the theoretical values. The minimum testing time is 1423 seconds, when N=105. The other discrepancy is that the measured data is not monotonically decreasing with increasing N values. The major source of discrepancy between the measured and theoretical data is thought to be due to the head seek time. As discussed earlier in Sec. 3.1, the head seek time is a variable quantity, but due to the lack of appropriate modeling, we simple used the average 40 msec seek time in our model. We computed the "measured" average seek time for each different N value by substituting the measured T_{total} and N value back to Eqs. (11), (6), and (9), to solve for T_{seek}. The results were shown in Fig. 5. It can be seen that the "measured" average seek time is always lower than 40 msec. These "measured" average seek times were used to compute the theoretical curve for the following two systems.

4.2 Two MO drives connected to a computer through two SCSI host adaptor cards

The testing times per disk for various N values were shown in Fig. 6. The curve with triangles is the theoretical curve based on Eq. (11) with "measured" average seek time, and the curve with x is the measured data. It can be seen from Fig. 6 that with the modified theoretical curve, the measured data is almost the same as the theoretical curve. Compared with Fig. 4, the testing time almost does not change at all, meaning the two MO drives are truly working in parallel. The minimum testing time is 1425 seconds, when N=105, an increase of 2 seconds compared to the single MO drive case.

4.3 Two MO drives connected to a computer through one SCSI host adaptor cards in daisy-chain manner

According to SCSI standard, each SCSI bus can support 7 SCSI devices in daisy-chain manner. To study the effect of putting more than one drive on the same SCSI bus, we connected two MO drives in the way shown in Fig. 7. The testing times per disk for various N values were shown in Fig. 8. The curve with triangles is the theoretical curve based on Eq. (11), and the curve with x is the measured data. It can be seen from Fig. 8 that the measured data is again almost the same as the theoretical curve. Compared with Figs. 4 and 6, the testing times differ when N is less than 30. When N is larger, the testing time is about 80 seconds larger than that of the previous two systems, indicating that there may be some conflicts on the SCSI bus data transfer. The minimum testing time is 1509 seconds, when N=95.

5. DISCUSSIONS

From the experimental data, the SCSI bus can be a bottleneck in system performance. When two MO drives were connected on a SCSI bus, the testing time increased by about 5%. When more drives are added, this will definitely become worse. The SCSI bus data transfer rate can be increased from 2 Mbyte/sec to 5 Mbyte/sec when operated in synchronous mode. This will be tested in the future. The other potential bottleneck is the DMA data rate. Using 32-bit VESA Local (VL) bus can double the DMA data rate. Besides using a PC with VL bus, the SCSI host adaptor card must also support VL bus. Both are more expensive hardware, but considering the performance increase, this solution is quite cost-effective. A third improvement that can be made is to cut down the CPU time in performing the byte comparison. This can be done either by using a higher speed PC, such as 486DX-66 or Pentinum based PC, or writing this part of the testing program in assembly language. A MO drive with higher rotation rate will also help in cutting down the testing time. With the system hardware used in this study, the optimal system configuration is 6 MO drives per PC. The maximum number of MO drives can be connected to a PC is limited by the fact that the maximum number of SCSI host adaptors can be inserted in a PC is 3, thus the maximum MO drives is 21. Our future work is to push the optimal configuration to 21 MO drives.

6. CONCLUSION

A low cost byte error rate testing system for 90mm magneto-optic (MO) disks had been developed. An IBM compatible 486-DX33 PC was used as the controller. A model was developed to predict the testing system performance based on the DMA data rate, SCSI bus data rate, MO drive data rate, access time, processor speed, and the number of sectors, N, involved in each read/write operation. Three system configurations were tested: (1) only one MO drive; (2) two MO drives are connected to PC through separate SCSI controller; and (3) two MO drives connected to PC through one SCSI controller in daisy-chain manner. The testing time of a disk varies from 40 min. to 24 min. when N is varied from 20 to 109. These testing times include the 10 min. of formatting time which is independent of N. The average access time of the MO disk was found to depend on the number of sectors involved in each read/write operation. Also, the measured access time is always lower than the specified 40 ms. Based on the measured access time, a refined model was used to predict the optimal cost/performance configuration. A system with 6 or 7 MO disk drives connected to a PC was found to have the best cost/performance ratio. With improvements in the hardware and software, the optimal system configuration can support a larger number of MO drives.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

1. SCSI specification, Sony corporation, (1992)

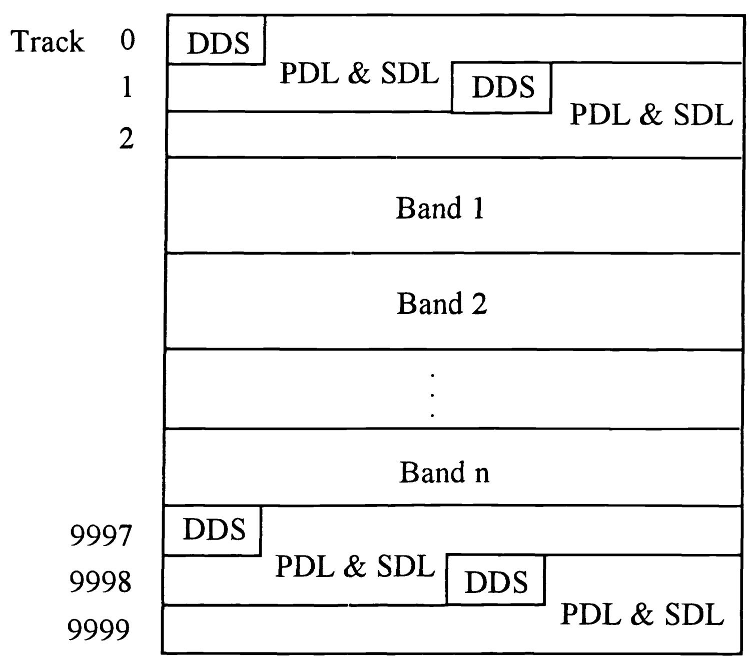

Fig. 1: The format of a 90mm, 128 Mbyte MO disk.

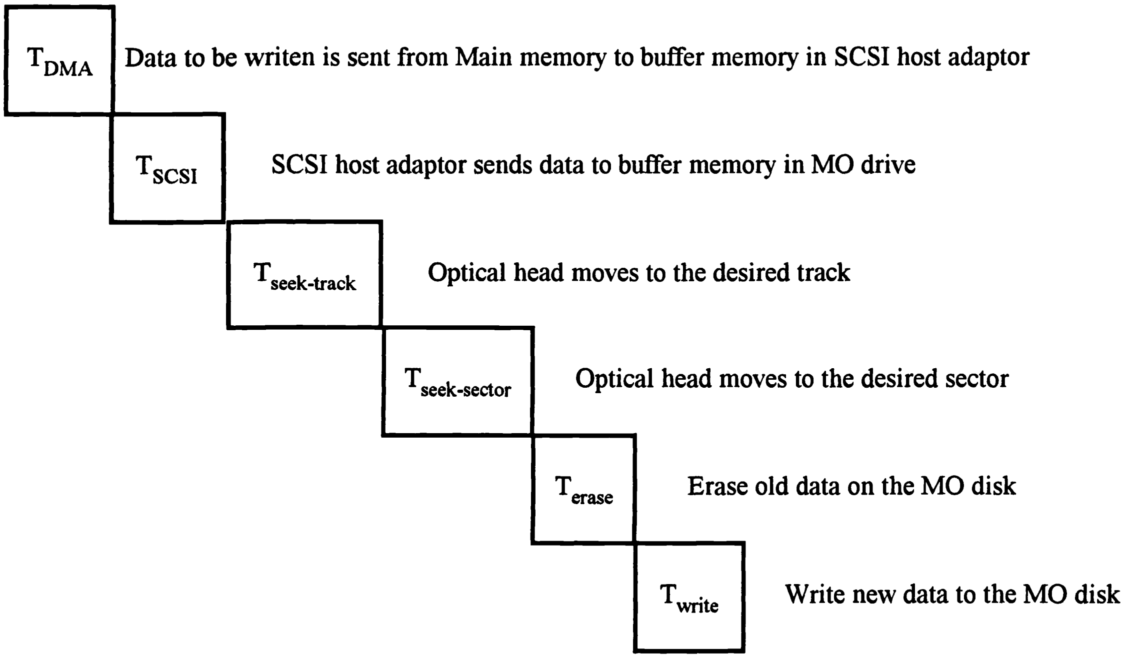

Fig. 2: The timing of the operations after the CPU issues a Write Long command to write N sectors of data to the MO disk.

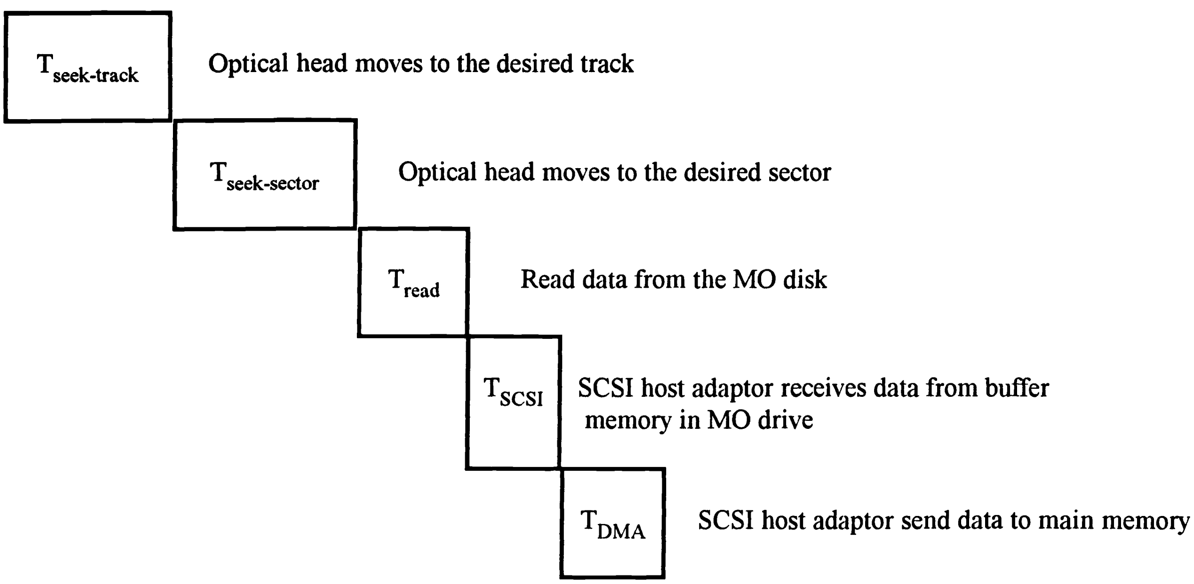

Fig. 3: The timing of the operations after the CPU issues a Read Long command to write N sectors of data to the MO disk.

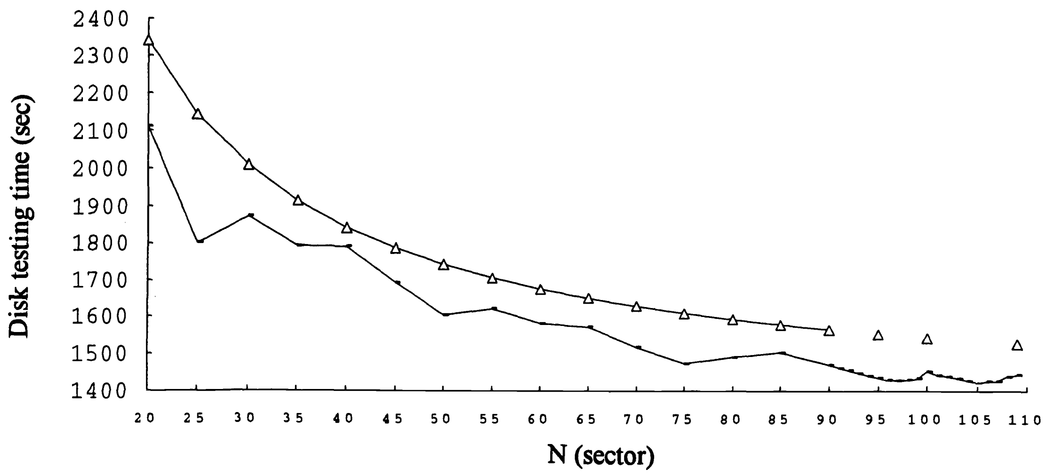

Fig. 4: The testing times per disk for various N values for the system with one MO drive. The curve with triangles is the theoretical curve, and the lower curve is the measured data.

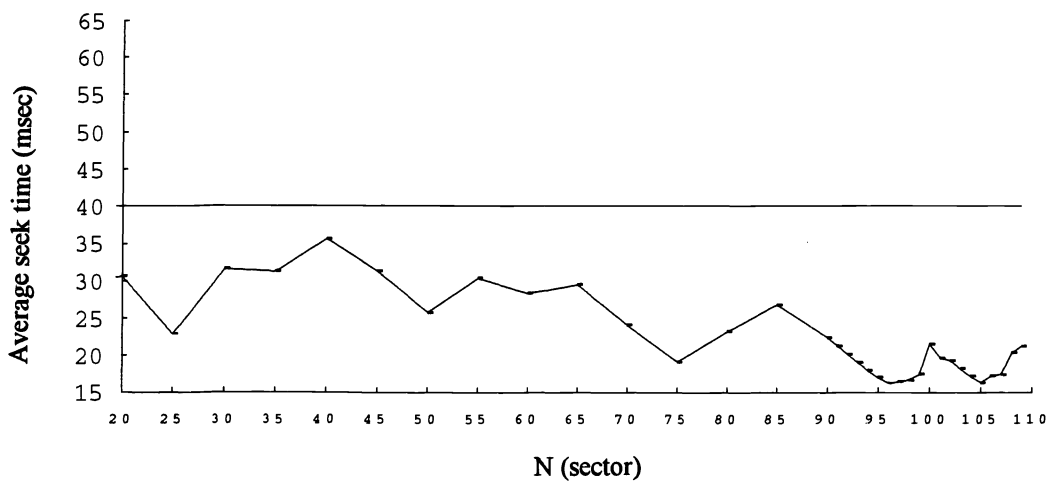

Fig. 5: The "measured" average head seek time for various N values. The specified average seek time is 40 msec.

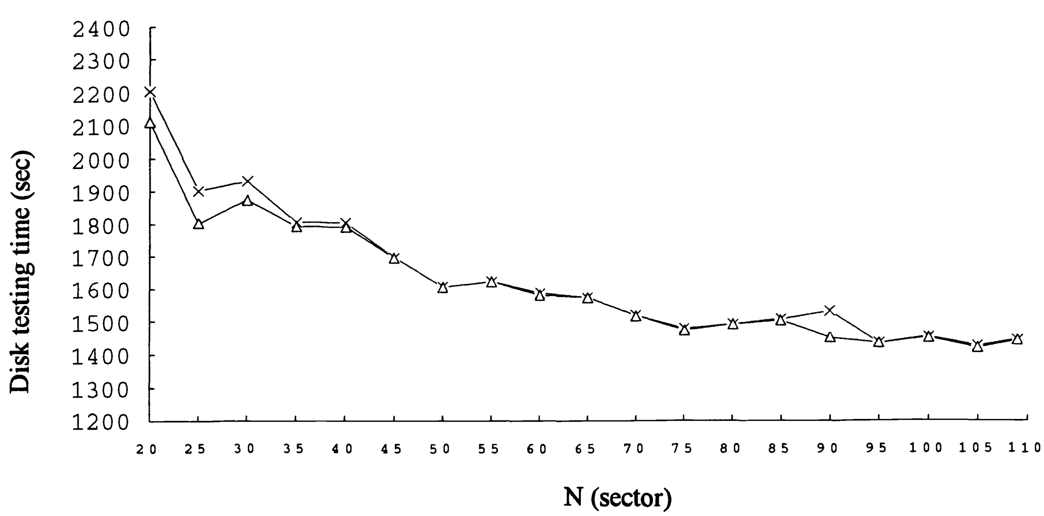

Fig. 6: The testing times per disk for various N values for the system with two MO drives and two SCSI bus. The curves with triangles and x are the theoretical and measured curves, respectively.

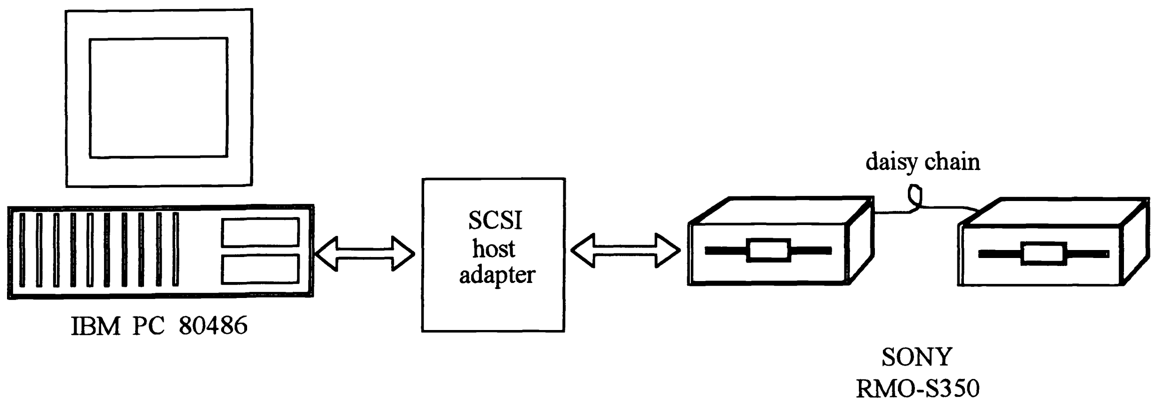

Fig. 7: The block diagram showing the daisy-chained SCSI configuration with two MO drives.

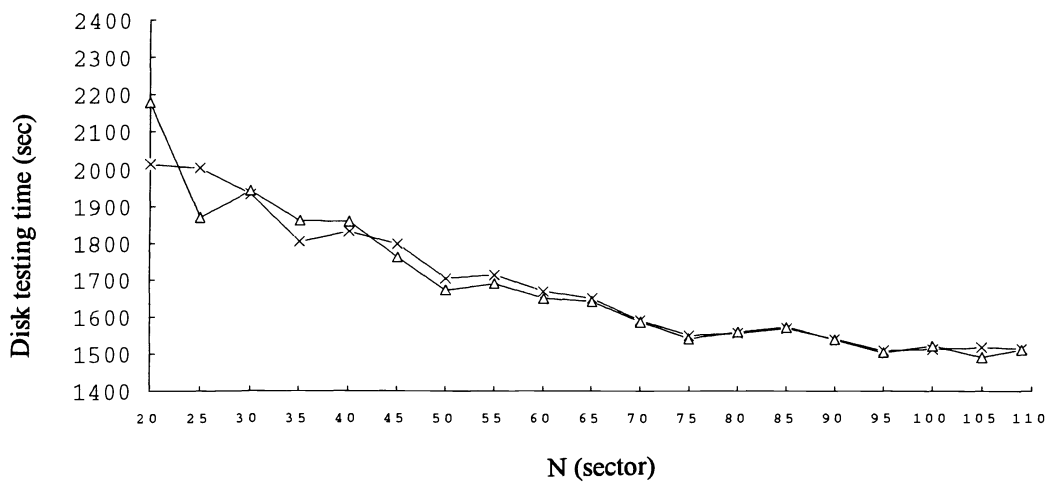

Fig. 8: The testing times per disk for various N values for the system with two MO drives and one SCSI bus. The curves with triangles and x are the theoretical and measured curves, respectively.