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Accurate Track-Count Accessing of Optical Disk Drive

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In order to create a rapid accessing feature of optical disk drives, the optical head should be positioned as accurately as possible near the target track if seeking motion is desired. First, an accurate seeking span decision algorithm employed to predict the spiral tracks' rotational number during seeking is discussed. Second, a method of correcting a miscount in the number of crossing tracks for accurate track-count accessing is proposed. During the seeking operation, the method of correcting the track miscount can generate a virtual track-crossing pulse in real time when a track-crossing pulse is missed due to a distorted tracking error signal during seeking. These two methods are practically installed in a 130 mm International Organization for Standardization (ISO) format optical disk drive and effectively operated for accurate track-count accessing.

KEYWORDS: optical disk drive, seeking, direct accessing, track-count, ISO format, mirror zone, tracking error signal, track-crossing pulse, miscount

§1. Introduction

To use optical disk drives as computer peripheral instruments, it is necessary to have a higher accessing function in order to search data rapidly. To reduce the accessing time in the optical disk drive, some direct accessing methods have been developed, which use the pregrooves on the disk surface instead of external scales to detect both the optical head movement and velocity.[1-3] Since the track pitch of an optical disk is much smaller than the resolution of the external scale, more accurate head positioning can be achieved. These methods, however, have the disadvantage of possibly miscounting the number of tracks crossed when the tracking error signal is disturbed by preformatted data or a mirror zone at the header area. This frequently results in time-consuming reseeking. To reduce the accessing time, it would be advantageous to position the optical spot near the target track as accurately as possible during the initial macroseeking.

This paper discusses a rapid accessing method that can accurately count the number of tracks crossed during seeking and precisely position the optical spot near the target track. It first describes the algorithm that determines the seeking span by predicting the rotational number of the spiral tracks during seeking. Second, it discusses the method of correcting the miscount in the number of tracks crossed which occurs during seeking. Finally, it proposes that these methods can be installed in an International Organization for Standardization (ISO) format 130 mm optical disk drive and operated effectively. In this paper, "seeking" is used to mean searching a destination track and "accessing" is used to mean searching a target track and a target sector. Seeking time added to latency is accessing time.

§2. Accurate Seeking Span Decision Algorithm

Since an optical disk has a spiral track structure, the optical spot cannot be positioned at the target track even if the number of tracks crossed is counted correctly. Figure 1 illustrates the spot locus on a disk during macroseeking. The disk is assumed to rotate once while looking for 2 tracks, for convenient explanation in the figure. When the spot traverses 2 tracks from the inner to outer direction, from Tr. 4 to Tr. 6, the first track-crossing point is the target track. On the other hand, when the spot seeks 2 tracks in the opposite direction, from Tr. 4

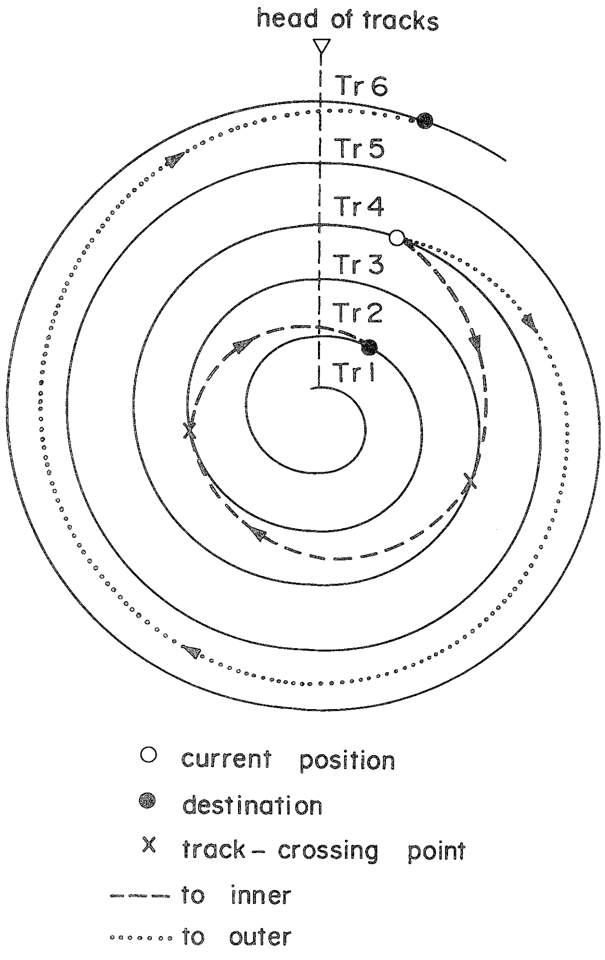

Fig. 1. Spot locus on spiral tracks.

to Tr. 2, the third track-crossing point corresponds to the destination. Therefore, the seeking span is 1 track in the former case, and 3 tracks in the latter case. Accordingly, for accurate track-count accessing, the seeking span needs to be adjusted for the number of disk rotations during seeking so that the spot does not overrun the target track to an outer track when seeking in the inner-to-outer circumference direction, or so that the spot does not stop at a track before the destination when seeking in an outer-to-inner direction.

Since the required time for macroseeking can be estimated beforehand, the number of disk rotations during macroseeking can also be estimated when an approximate seeking span is determined from the distance between the target track and the current track. Practically, an accurate macroseeking span, N_{seek}, is determined according to the following algorithm. When an 130 mm-diameter ISO-format optical disk is used, the difference between the target address and the current one is converted to the number of sectors, N_{sct}. The N_{sct} divided by the number of sectors per track, K_{sct}, gives the number of tracks, N_{trk}, with the number of residual sectors, R_{sct}, left over, as follows:

$$\pm N_{sct} = \pm K_{sct} \times N_{trk} + R_{sct} \tag{2.1}$$

(+: when seeking inner to outer; −: outer to inner),

where

$K_{sct} = 17$(1024 Bytes/sector disk), or

31(512 Bytes/sector disk),

and

$$N_{trk} \geqq 0, \qquad R_{sct} \geqq 0.$$

On the other hand, the required time to cross N_{trk} tracks can be predetermined before the start of the seeking motion by referring to the measured relationship between the seeking time and the seeking span, as shown in Fig. 2. Since the velocity of the optical spot is controlled so that it follows the target velocity recalled from a read-only memory (ROM), in real time, the measured relationship given in Fig. 2 is almost independent of environmental change such as temperature. Also, the disk rotational speed is known, which means the total number of disk rotation sectors, S_{rot}, during macroseeking can be estimated in advance. By converting the number of sectors, S_{rot}, to the number of tracks, N_{rot}, the following equation is obtained:

$$S_{rot} = K_{sct} \times N_{rot} + R_{rot} \tag{2.2}$$

where

$$N_{rot} \geqq 0 \qquad \text{and} \qquad R_{rot} \geqq 0.$$

Then, an accurate seeking span, N_{seek}, which takes into account the number of disk rotations during seeking, is given by the following equation:

$$N_{seek} = N_{trk} \mp (N_{rot} + N_{cmp}) \tag{2.3}$$

(−: when seeking inner to outer; +: outer to inner),

where

IF $R_{rot} > R_{sct}$ THEN $N_{cmp} = 1$, or

IF $R_{rot} \leqq R_{sct}$ THEN $N_{cmp} = 0$.

The longer the seeking span is, the larger $N_{rot} + N_{cmp}$ becomes. $N_{rot} + N_{cmp}$ corresponds to 4 or 5 in the case of full-stroke seeking.

§3. Crossing Track Miscount Correction Method

3.1 *Algorithm*

Accurate detection of track-crossing is essential in the direct accessing method because the method uses pregrooves on the disk to detect the number of tracks crossed and the crossing velocity. Tracking error signals disturbed by preformatted data in header areas can be rectified by using an appropriate waveform-shaping circuit.[1)] Figure 3 shows a sector format for 512 userbytes of a 130 mm ISO-format disk.[4)] The field of the offset detection flag (ODF) is prescribed to be a mirror zone with neither pregrooves nor preformatted data, by the ISO format in Fig. 3. Therefore, the pregrooves are discontinued at an ODF which has a length of one userbyte for detecting a tracking offset on all header areas. When an optical

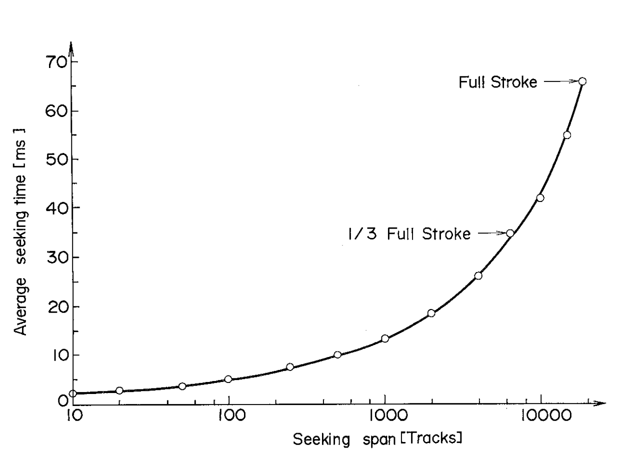

Fig. 2. Measured seeking time vs. seeking span when a 130 mm ISO-format disk is used. This figure is used for estimating the number of rotational tracks during seeking prior to the start of seeking operation.

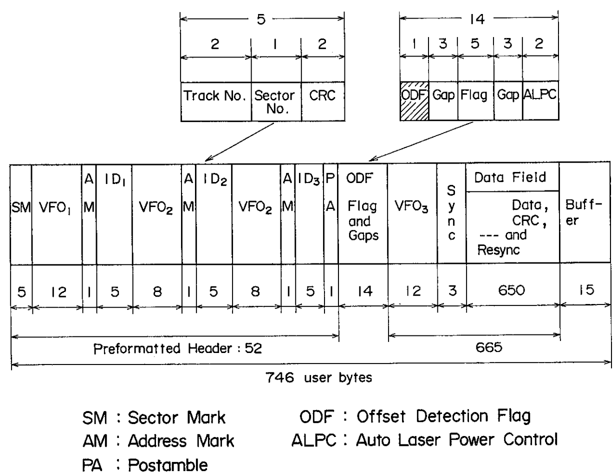

Fig. 3. Sector format for 512 userbytes of a 130 mm ISO-format disk. Offset detection flag, which has a length of 1 userbyte, is a mirror zone.

spot crosses a mirror zone rapidly, the tracking error signal is distorted and the center of the track cannot be detected, as shown in Fig. 4. Thus, the following miscount correction method has been developed to accurately count the number of tracks crossed during the seeking operation. First, this method always measures the crossing periods over two tracks, T_k and T_{k-1}, just prior to the track being crossed during seeking. Then a virtual track-crossing pulse is generated at the moment when the crossing period of the track being crossed, T, satisfies

$$T \geqq 1.5 \times (T_k + T_{k-1})/2. \tag{3.1}$$

This method utilizes the fact that only one track is missed during track detection. Such track detection omission occurs during fast movement, and the fluctuation of the track-crossing period during fast movement is very small even during acceleration or deceleration. If the next track center cannot be detected during the current track-crossing period, T exceeds one and a half times $(T_k+T_{k-1})/2$, the crossing track being detected is considered miscounted and one virtual track-crossing pulse is then inserted. If the next track center is detected within the crossing period of the track being crossed, T satisfies eq. (3.1) and a virtual track-crossing pulse is not generated. If a miscount occurs for two or more consecutive tracks, only the first track can be corrected.

3.2 *Conditions for proper operation*

When the previous track-crossing period, T_k is misread at the mirror zone and detected as shorter than the true value, an excessive virtual pulse may be generated. To avoid the generation of an excessive pulse due to an operational error in the logic circuit used for miscount correction, the previous two track-crossing periods are averaged.

An excessive virtual track-crossing pulse is also generated when the track-crossing period varies rapidly due to a large acceleration, even if track detection omission does not occur. Now, let us calculate the rate of change for the track-crossing period during acceleration or deceleration, and determine the applicability of the averaging process. Figure 5 describes the track-crossing pulses during deceleration. In this figure, T_{av} is defined by

$$T_{av} \triangleq (T_k + T_{k-1})/2. \tag{3.2}$$

The movement of the spot is given by the following equations by using eq. (3.2):

$$(v_{k-1} - \alpha T_{av})T_{av} = L_t \tag{3.3}$$

$$(v - \alpha T)T = L_t, \quad \text{and} \tag{3.4}$$

$$v = v_{k-1} - 2\alpha T_{av}, \tag{3.5}$$

where

L_t: track pitch (m),
α: deceleration of the spot (m/s^2),
v_{k-1}: track-crossing velocity at t_{k-1} (m/s),

and

v: track-crossing velocity at t (m/s).

Equation (3.3) means that the spot moves $2L_t$ in the distance from time t_{k-1} to t in Fig. 5. Equation (3.4) gives the moving distance of the spot from time t to $t+T$. Equations (3.3)–(3.5) can be used to determine the degree of change of the track-crossing period, T/T_{av}, which is determined by the acceleration, α, and the track-crossing velocity, v_{k-1}. The computed relationship between T/T_{av} and v_{k-1} is plotted in Fig. 6 when the values $L_t = 1.6 \times 10^{-6}$ (m) and $\alpha = 60$ (m/s^2) are substituted for eqs. (3.3)–(3.5). If $T/T_{av} < 1.5$ is satisfied in Fig. 6, no excessive pulse is generated. When the value $v_{k-1} = 0.1$ m/s is assigned to Fig. 6, $T/T_{av} \fallingdotseq 1.014$ is obtained. This means that the track-crossing period changes less than 1.4% when the velocity of the optical spot is over 0.1 m/s. As will be described later, it is recognized that the miscount at the mirror zone occurs for a 130 mm-diameter disk rotating at 2400 rpm when the track-crossing velocity exceeds 0.3 m/s. Hence, the degree of change of the track-crossing period resulting from high acceleration or deceleration may not cause an excessive pulse generation if virtual pulse generation is suspended during low-speed movement below 0.1 m/s.

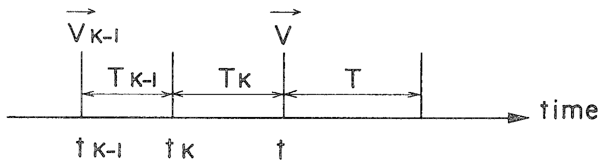

Fig. 5. Track-crossing pulses during deceleration. Track-crossing periods T_{k-1} and T_k are always memorized in the drive.

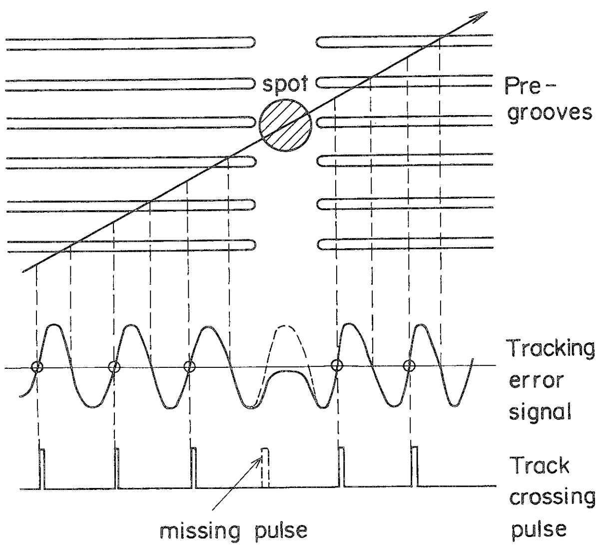

Fig. 4. Pregrooves are discontinued at every mirror zone in header areas. Track crossing is not detected when the optical spot crosses a mirror zone of an ISO-format disk at high speed.

3.3 *Experimental results*

To investigate the performance of the track miscount correction method, a macroseeking operation was conducted using a 130 mm-diameter ISO-format optical disk. The revolution of the disk was 2400 rpm. Figure 7 shows results from an actual operation of the miscount

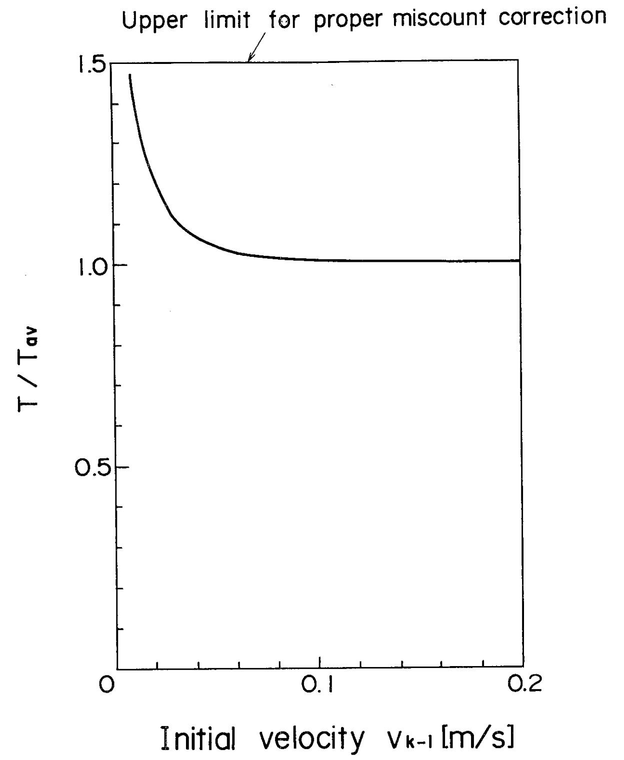

Fig. 6. Degree of change of track-crossing period T/T_{av} vs initial velocity v_{k-1} when the head acceleration is 60 m/s^2. Track-crossing period T seldom changes during one track crossing at high speed because T is nearly equal to T_{av}.

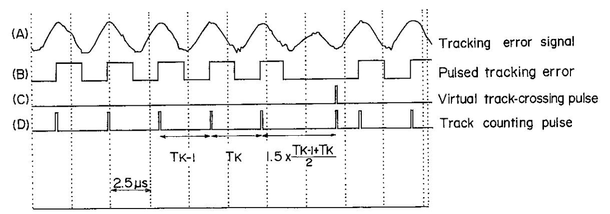

Fig. 7. Virtual track-crossing pulse generation by a miscount correction circuit.

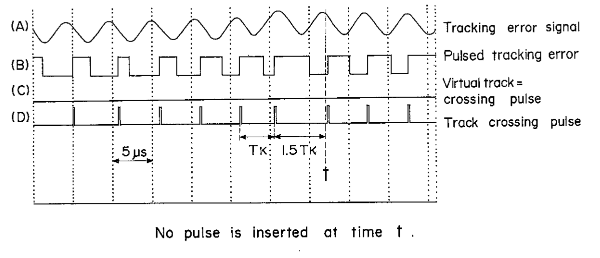

Fig. 8. No operation of miscount correction circuit. No excessive virtual pulse is generated at time t.

correction circuit. A virtual pulse is added between real track-crossing pulses when the spot traverses a mirror zone.

Figure 8 shows the effect of the averaging process of the track-crossing periods. In fact, if

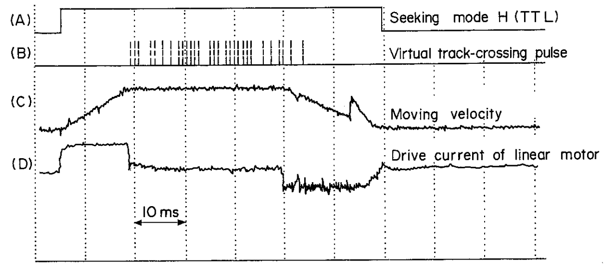

Fig. 9. Operation of correcting track miscounts during full-stroke seeking. Virtual track-crossing pulses were generated when the track-crossing velocity was over 0.3 m/s, and a total of 29 pulses were generated, one in nearly every sector-crossing time, while moving near the maximum speed, 0.6 m/s.

$$T \geqq 1.5T_k \tag{3.6}$$

is adopted in Fig. 8 instead of eq. (3.1), an unnecessary virtual pulse is outputted before detecting the track center, and one excessive crossed track would be counted; however, the averaging process described in eq. (3.1) prevents the logic circuit from operating incorrectly.

A full-stroke seeking operation was performed to investigate the number of virtual pulses generated during seeking, as shown in Fig. 9. Virtual track-crossing pulses were generated when the track-crossing velocity was over 0.3 m/s, and were generated in nearly every sector-crossing time while moving near the maximum speed, 0.6 m/s, and a total of 29 pulses were inserted between detected track-crossing pulses. If no virtual track-crossing pulse is generated, about thirty track positioning errors will occur during the first macroseeking operation, which would result in several milliseconds added to the reseeking time.

§4. Random Accessing Test

To evaluate the comprehensive performance of the accurate seeking span decision algorithm and track miscount correction method discussed in §2 and §3, the random accessing test was carried out half a million times. Figure 10 shows the distribution of the positioning error

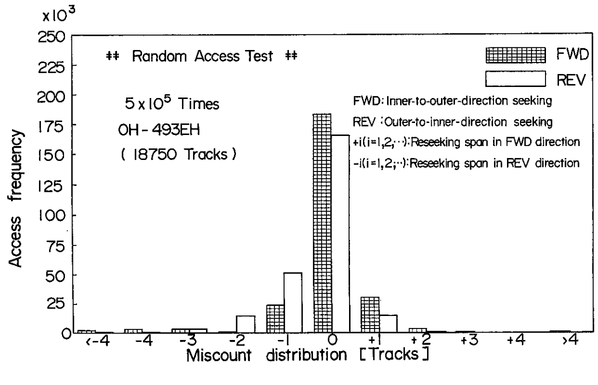

Fig. 10. Distribution of positioning error at first macroseeking in the case of half a million random accessing tests. FWD: Inner-to-outer-direction seeking, REV: Outer-to-inner-direction seeking, +i(i=1, 2,···): Reseeking span in FWD direction, −i(i=1, 2,···): Reseeking span in REV direction.

during the first macroseeking operation at each accessing command. The optical spot was sent to the target track with approximately 70 percent accuracy within the first macroseeking and positioned within plus/minus one track with an accuracy of 90 percent or more.

§5. Conclusions

An effective means of reducing disk drive accessing time is to position the optical spot as close as possible to the target track in the first macroseeking operation. To do this, an accurate seeking span decision algorithm and a track miscount correction method were proposed and successfully implemented in a 130 mm ISO-format optical disk drive to demonstrate their effectiveness. As a result, several milliseconds of unnecessary reseeking time were saved. These techniques are applicable not only to 130 mm optical disk drives but also to 90 mm optical disk drives.

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