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Tsuruya et al.

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(54) **STORAGE SYSTEM**

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
G06F 3/06 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 3/0608*** (2013.01); ***G06F 3/0616*** (2013.01); ***G06F 3/0659*** (2013.01); ***G06F 3/0683*** (2013.01)

(58) **Field of Classification Search**
CPC G06F 3/0608; G06F 3/0616; G06F 3/0659; G06F 3/0683
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

11,210,032 B1	12/2021	Nagao et al.		
2008/0144079 A1*	6/2008	Pandey	H03M 7/30 358/1.15	
2012/0260009 A1*	10/2012	Lu	G06F 3/0679 710/52	
2016/0342545 A1*	11/2016	Arai	G06F 11/0727	

* cited by examiner

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(57) **ABSTRACT**

A storage system includes a controller and one or more storage devices, and the controller can compress data in different compression units, and collectively compresses data of one or a plurality of consecutive addresses in each compression unit of the different compression units. The controller receives write data, determines whether read of data stored in the one or more storage devices is necessary for compression of the write data by a first compression unit, determines compression of the write data in the first compression unit when read is not necessary, and determines compression in the first compression unit or compression in a second compression unit smaller than the first compression unit based on a remaining endurance of rewriting of the one or more storage devices when read is necessary.

12 Claims, 20 Drawing Sheets

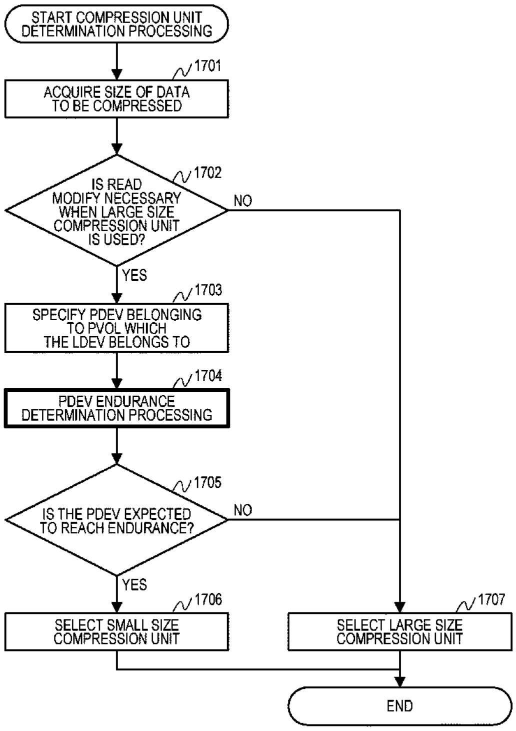

START COMPRESSION UNIT DETERMINATION PROCESSING
1701
ACQUIRE SIZE OF DATA TO BE COMPRESSED
1702
IS READ MODIFY NECESSARY WHEN LARGE SIZE COMPRESSION UNIT IS USED?
NO
YES
1703
SPECIFY PDEV BELONGING TO PVOL WHICH THE LDEV BELONGS TO
1704
PDEV ENDURANCE DETERMINATION PROCESSING
1705
IS THE PDEV EXPECTED TO REACH ENDURANCE?
NO
YES
1706
SELECT SMALL SIZE COMPRESSION UNIT
1707
SELECT LARGE SIZE COMPRESSION UNIT
END

FIG. 1

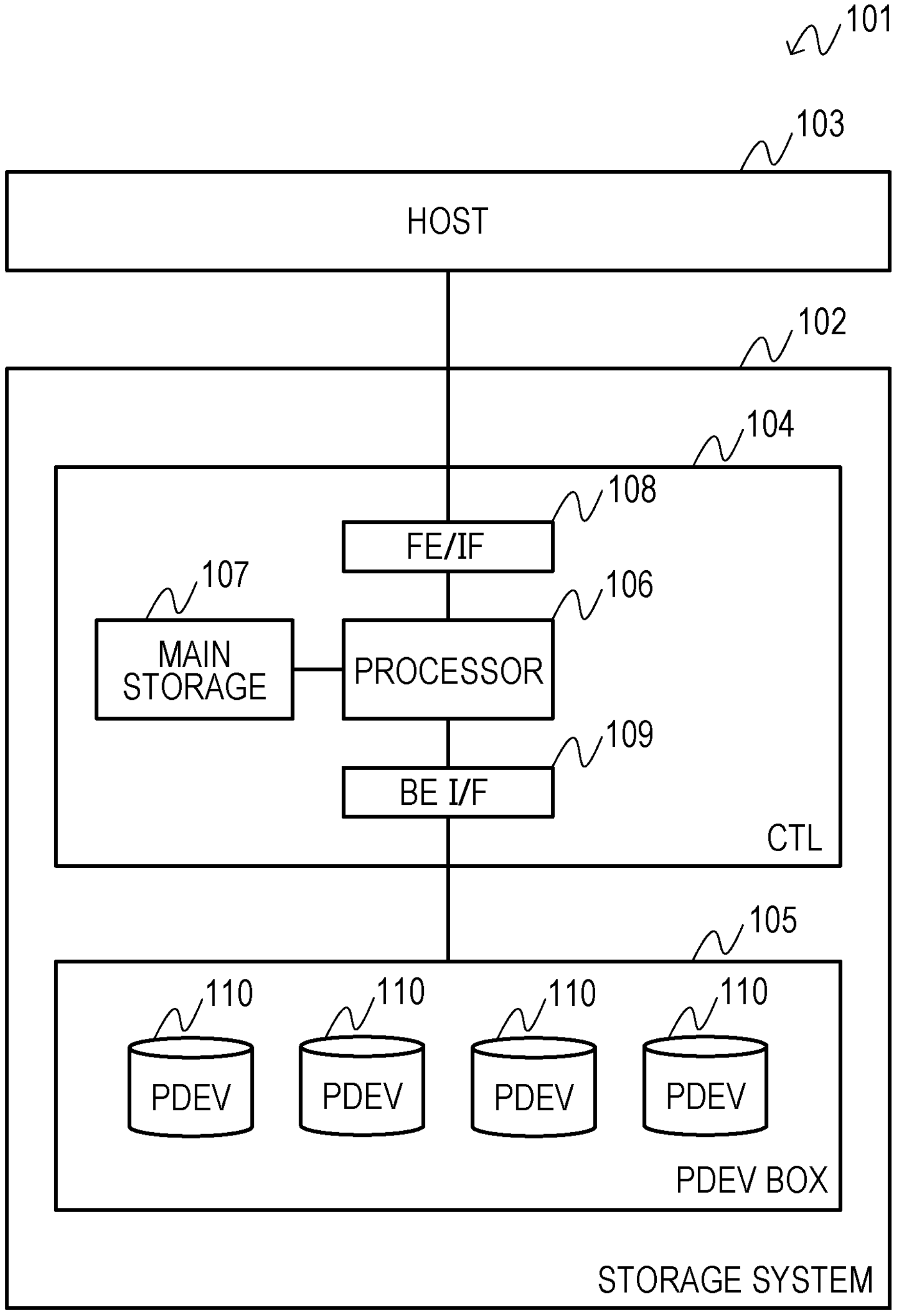

101
103
HOST
102
104
108
FE/IF
107
MAIN STORAGE
106
PROCESSOR
109
BE I/F
CTL
105
110
PDEV
110
PDEV
110
PDEV
110
PDEV
PDEV BOX
STORAGE SYSTEM

FIG. 2

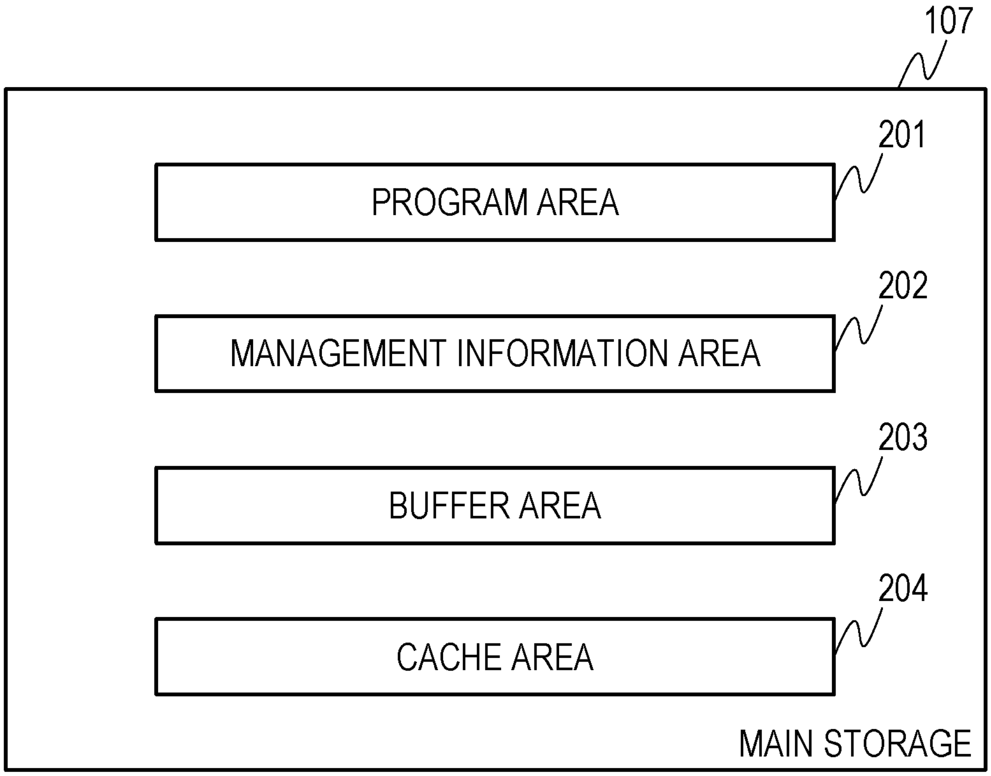

107
201
PROGRAM AREA
202
MANAGEMENT INFORMATION AREA
203
BUFFER AREA
204
CACHE AREA
MAIN STORAGE

FIG. 3

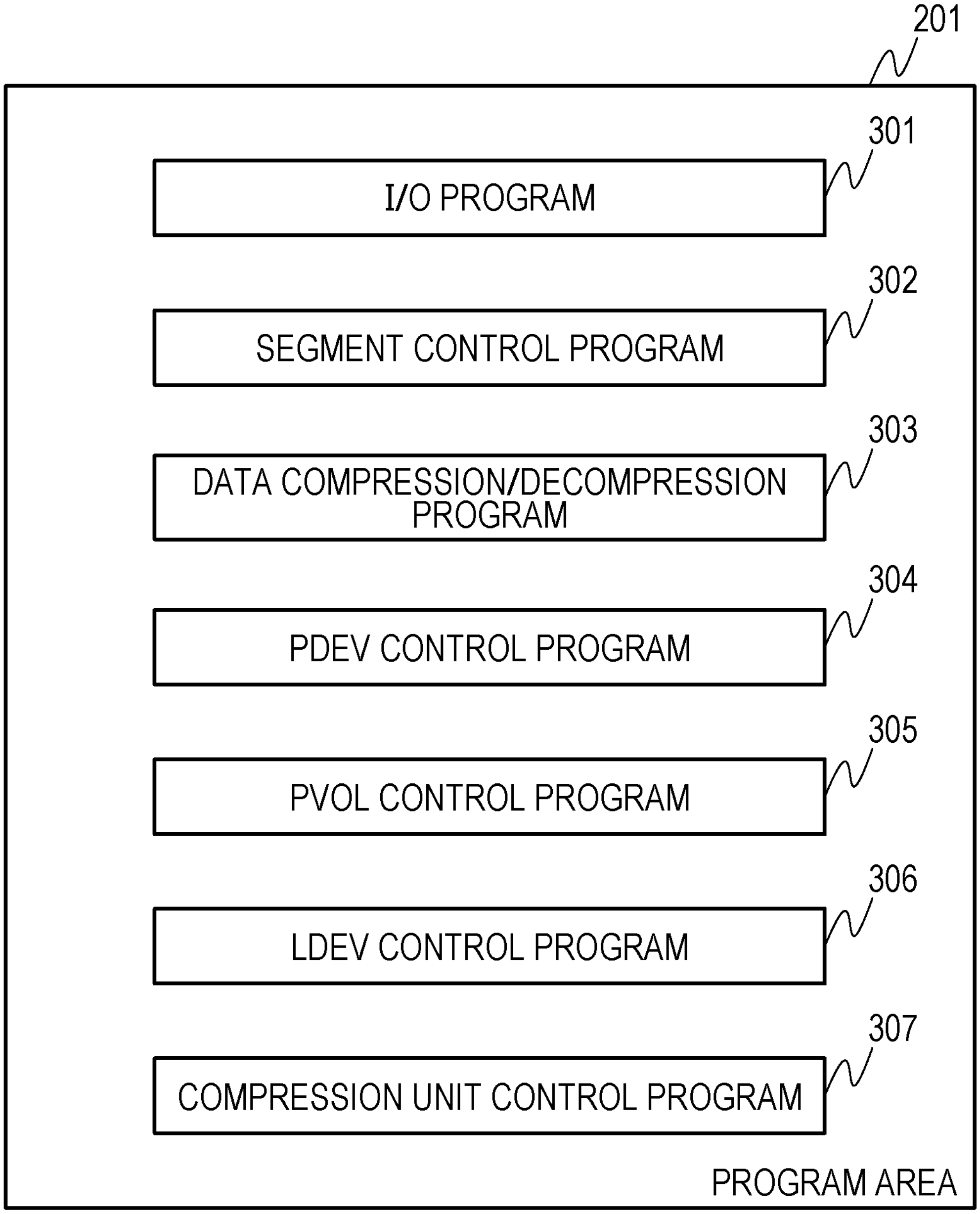

201
301
I/O PROGRAM
302
SEGMENT CONTROL PROGRAM
303
DATA COMPRESSION/DECOMPRESSION PROGRAM
304
PDEV CONTROL PROGRAM
305
PVOL CONTROL PROGRAM
306
LDEV CONTROL PROGRAM
307
COMPRESSION UNIT CONTROL PROGRAM
PROGRAM AREA

FIG. 4

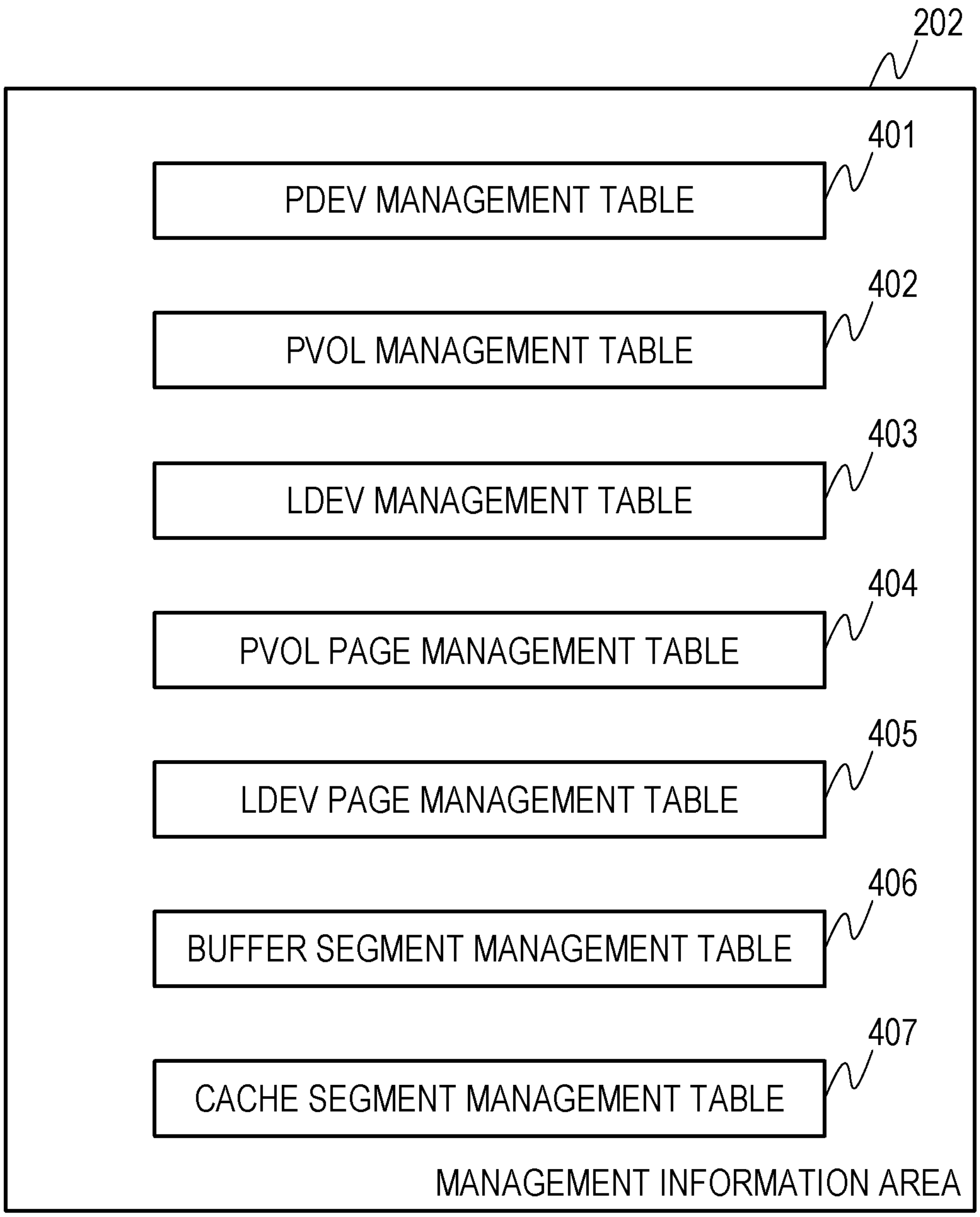

202
401
PDEV MANAGEMENT TABLE
402
PVOL MANAGEMENT TABLE
403
LDEV MANAGEMENT TABLE
404
PVOL PAGE MANAGEMENT TABLE
405
LDEV PAGE MANAGEMENT TABLE
406
BUFFER SEGMENT MANAGEMENT TABLE
407
CACHE SEGMENT MANAGEMENT TABLE
MANAGEMENT INFORMATION AREA

FIG. 5

401

501	502	503	504	505	506	507	508
PDEV #	CAPACITY	STATE	BELONGING PVOL #	WRITABLE CAPACITY	TOTAL WRITE CAPACITY	SCHEDULED OPERATING TIME	OPERATING TIME
1	3.2 TB	NORMAL	1	5,840 TB	642 TB	43,800 h	6,789 h
2	3.2 TB	NORMAL	1	5,840 TB	645 TB	43,800 h	6,789 h
...	...	...	...	...	...	...	...
N	l.m TB	ABNORMAL	V	W	X	Y	Z
...	...	...	...	...	...	...	...

PDEV MANAGEMENT TABLE

FIG. 6

402

601	602	603	604	605	606	607	608
PVOL #	USED CAPACITY / TOTAL CAPACITY	RECOMPRESSIBLE DATA RATIO	BELONGING LDEV #	STATE	REDUNDANT CONFIGURATION	BELONGING PDEV #	PVOL PAGE MANAGEMENT TABLE STORAGE ADDRESS
1	1.6/ 32.0 TB	20%	1, 3	NORMAL	1 PARITY	1, 2, 3, 4	0xABCD...
2	20.5/ 51.2 TB	15%	2, 4, 5	NORMAL	2 PARITIES	5, 6, 7, 8	0xEFGH...
...	...	...	...	...	...	...	...
N	ab.c/ de.f TB	g%	X	ABNORMAL	h PARITIES	Y	Z
...	...	...	...	...	...	...	...

PVOL MANAGEMENT TABLE

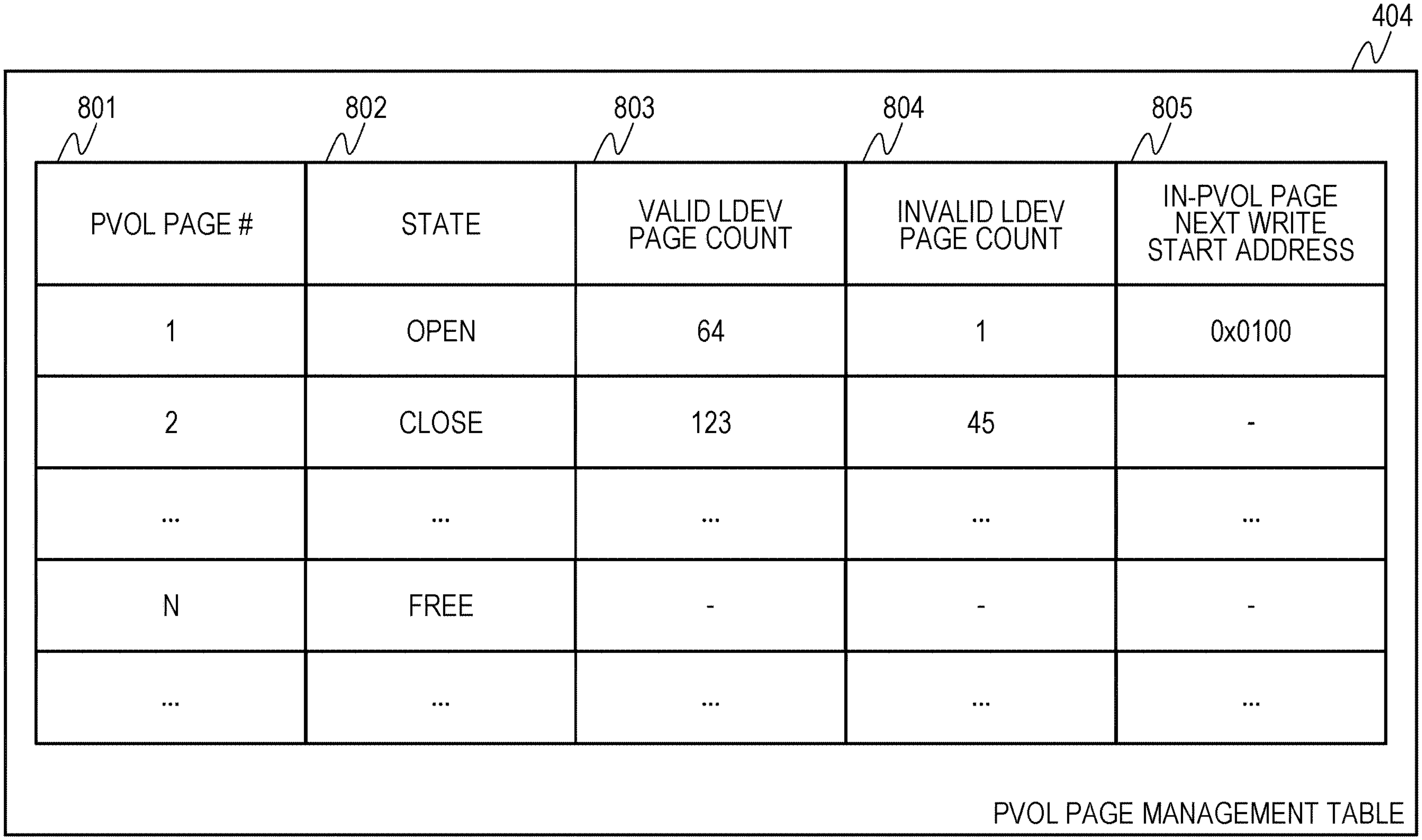
FIG. 7

403

701	702	703	704	705
LDEV #	CAPACITY	STATE	BELONGING PVOL #	LDEV PAGE MANAGEMENT TABLE STORAGE ADDRESS
1	2.0 TB	NORMAL	1	0xABCD...
2	4.0 TB	NORMAL	2	0xEFGH...
...	...	...	...	...
N	l.m TB	ABNORMAL	V	0xWXYZ...
...	...	...	...	...

LDEV MANAGEMENT TABLE

FIG. 8



404
801
802
803
804
805

PVOL PAGE #	STATE	VALID LDEV PAGE COUNT	INVALID LDEV PAGE COUNT	IN-PVOL PAGE NEXT WRITE START ADDRESS
1	OPEN	64	1	0x0100
2	CLOSE	123	45	-
...	...	...	...	...
N	FREE	-	-	-
...	...	...	...	...

PVOL PAGE MANAGEMENT TABLE

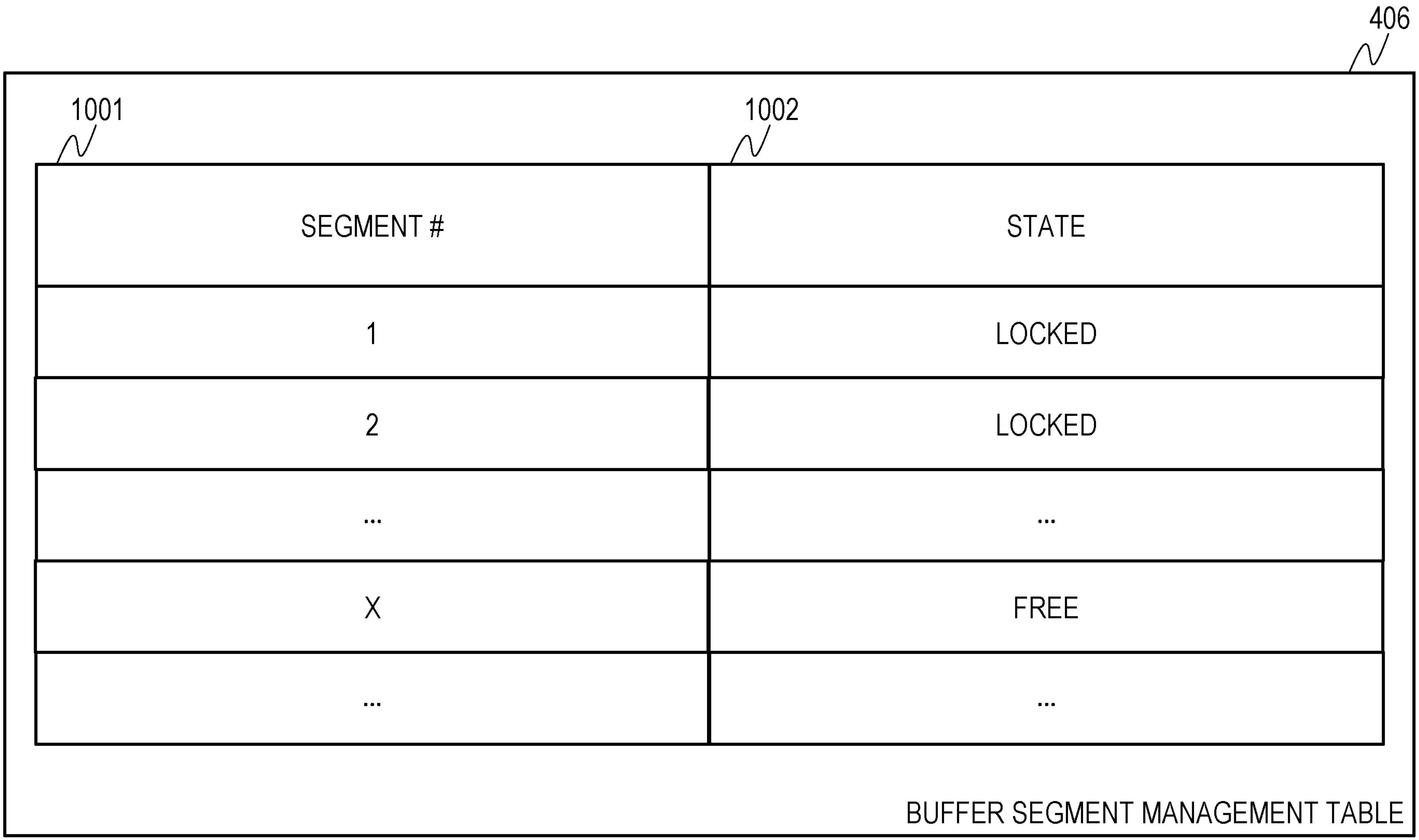
FIG. 9

405

901	902	903	904	905	906	907
LDEV PAGE #	STATE	ALLOCATION DESTINATION PVOL PAGE #	IN-PVOL PAGE START ADDRESS	COMPRESSION UNIT (LDEV PAGE COUNT)	COMPRESSED SIZE	IN-COMPRESSION DATA PAGE #
1	ALLOCATED	1	0x0000	4	0x0080	3
2	ALLOCATED	1	0x0080	1	0x0020	1
...	...	...	...	...	...	...
X	UNALLOCATED	-	-	-	-	-
...	...	...	...	...	...	...

LDEV PAGE MANAGEMENT TABLE

FIG. 10


406
1001
1002

SEGMENT #	STATE
1	LOCKED
2	LOCKED
...	...
X	FREE
...	...

BUFFER SEGMENT MANAGEMENT TABLE

FIG. 11

407

1101	1102	1103	1104	1105
SEGMENT #	STATE	DATA TYPE	ALLOCATION DESTINATION LDEV #	LDEV PAGE #
1	CLEAN	UNCOMPRESSED DATA	1	101
2	DIRTY	UNCOMPRESSED DATA	5	84
...	...	...	...	...
X	FREE	-	-	-
Y	DIRTY	COMPRESSED DATA	1	101, 102, 103, 104
...	...	...	...	...

CACHE SEGMENT MANAGEMENT TABLE

FIG. 12

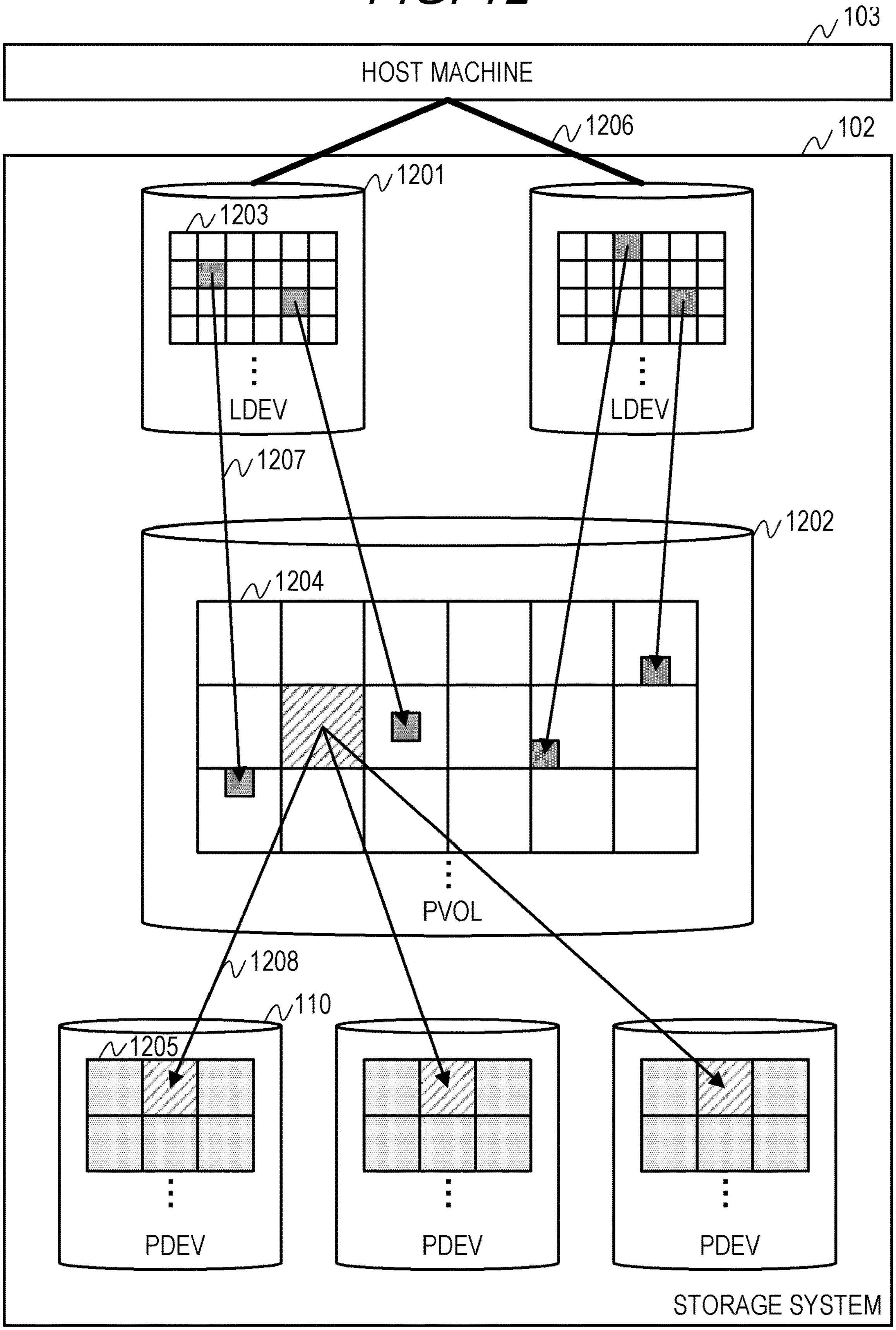

103
HOST MACHINE
1206
102
1201
1203
LDEV
LDEV
1207
1202
1204
PVOL
1208
110
1205
PDEV
PDEV
PDEV
STORAGE SYSTEM

FIG. 13

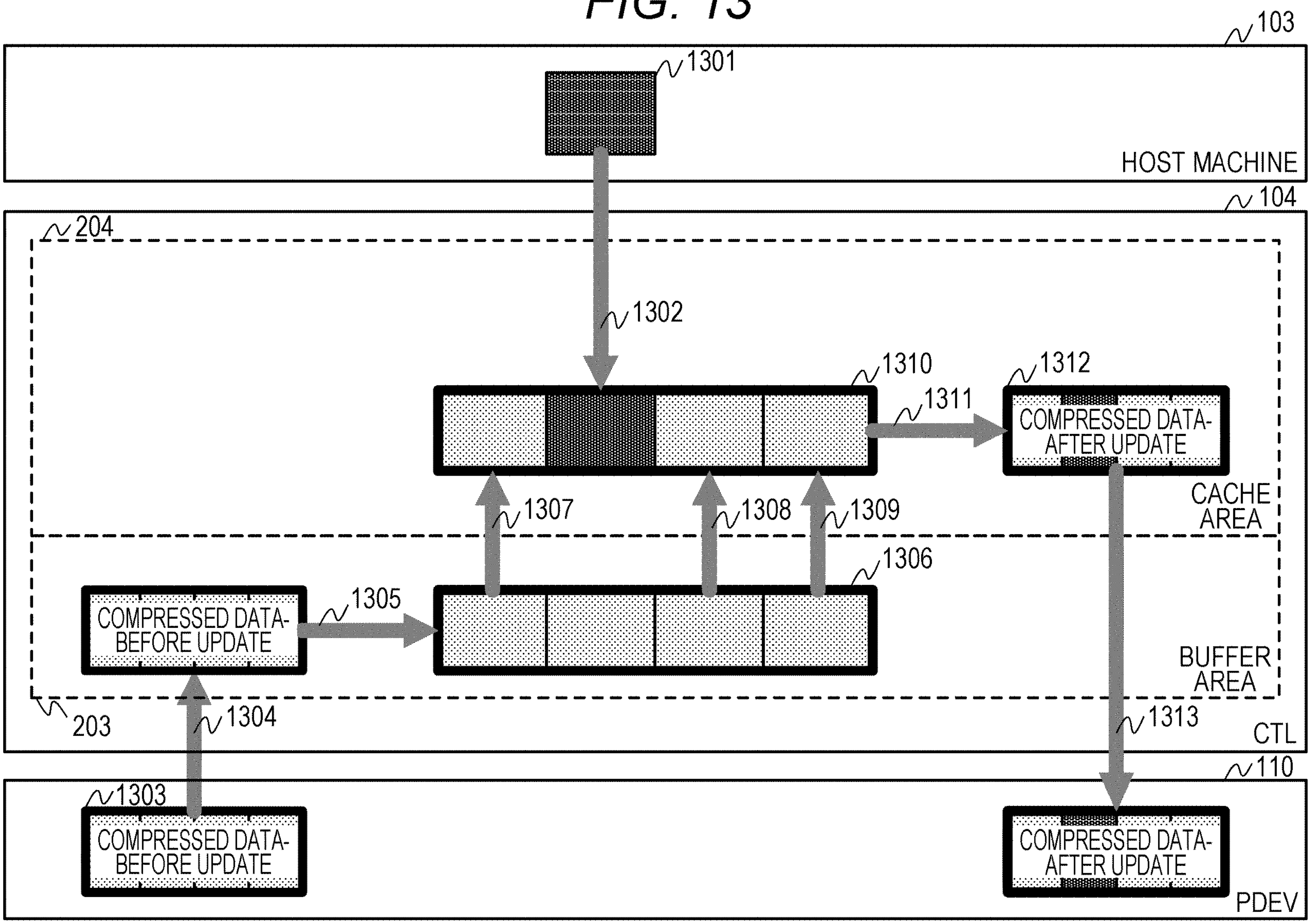

103
1301
HOST MACHINE
104
204
1302
1310
1312
1311
COMPRESSED DATA-
AFTER UPDATE
1307
1308
1309
CACHE
AREA
1306
1305
COMPRESSED DATA-
BEFORE UPDATE
BUFFER
AREA
203
1304
1313
CTL
110
1303
COMPRESSED DATA-
BEFORE UPDATE
COMPRESSED DATA-
AFTER UPDATE
PDEV

FIG. 14

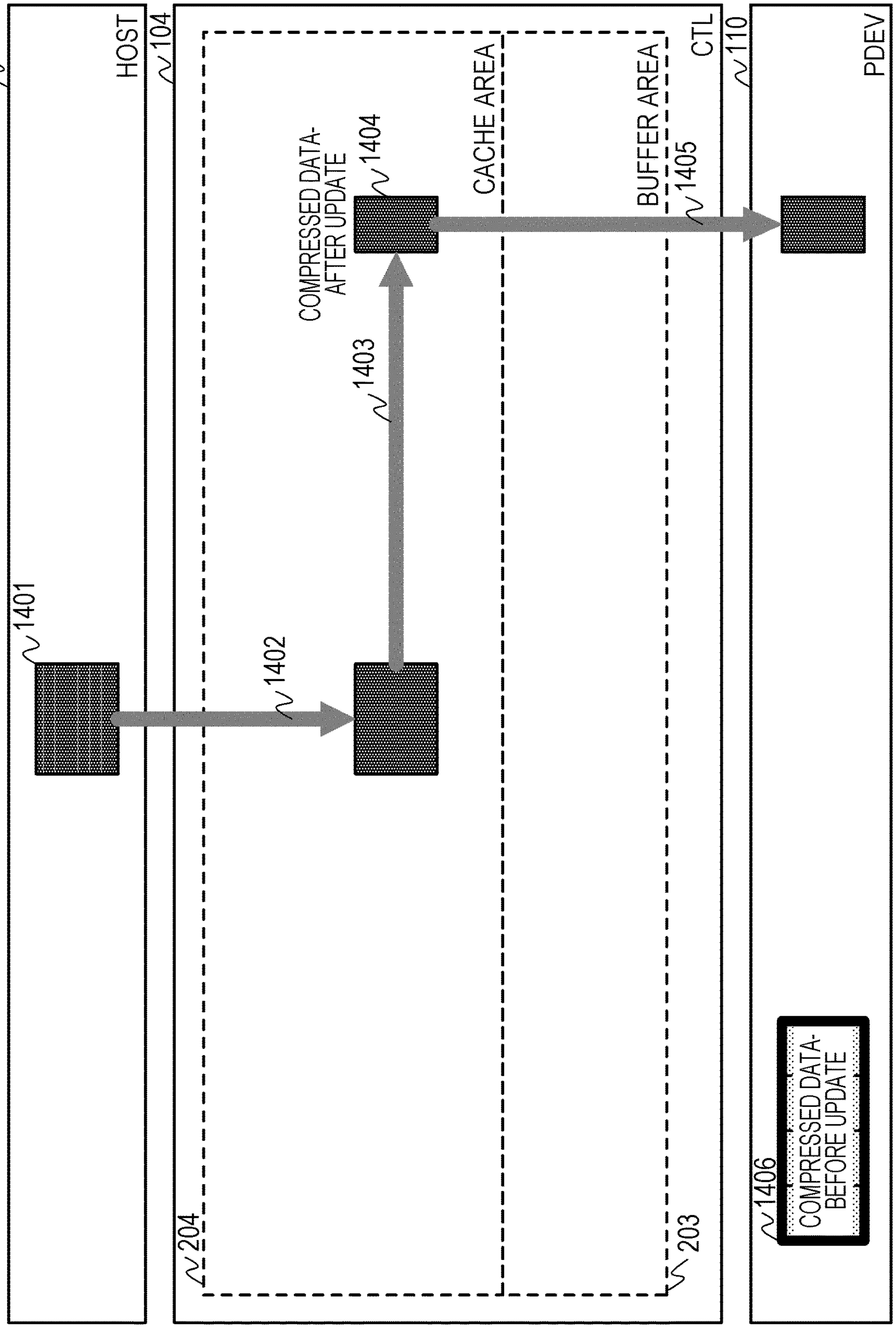

103
HOST
104
CTL
110
PDEV
1401
1402
1403
1404
COMPRESSED DATA-
AFTER UPDATE
CACHE AREA
BUFFER AREA
1405
204
203
1406
COMPRESSED DATA-
BEFORE UPDATE

FIG. 15

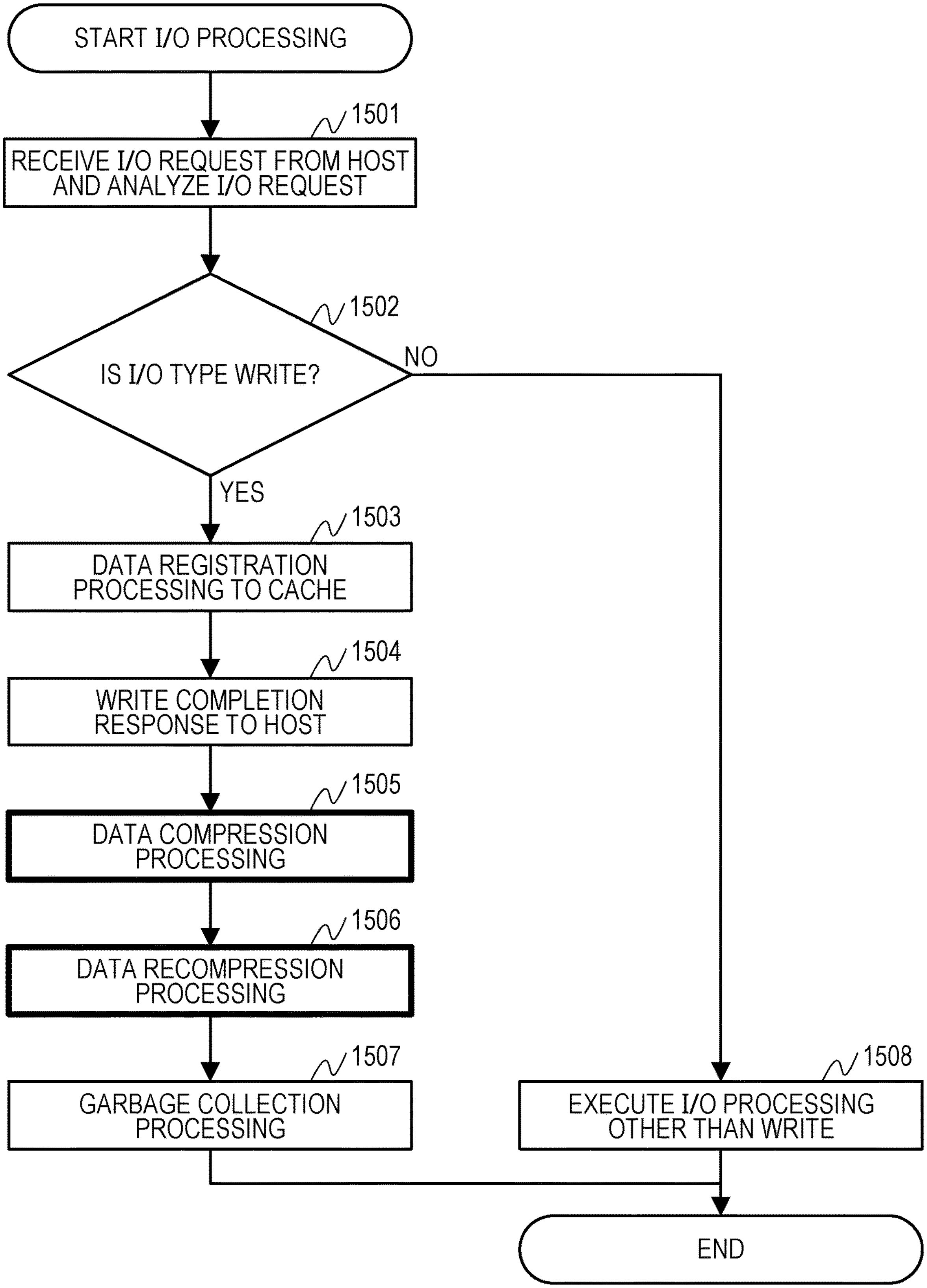

START I/O PROCESSING
1501
RECEIVE I/O REQUEST FROM HOST AND ANALYZE I/O REQUEST
1502
IS I/O TYPE WRITE?
NO
YES
1503
DATA REGISTRATION PROCESSING TO CACHE
1504
WRITE COMPLETION RESPONSE TO HOST
1505
DATA COMPRESSION PROCESSING
1506
DATA RECOMPRESSION PROCESSING
1507
GARBAGE COLLECTION PROCESSING
1508
EXECUTE I/O PROCESSING OTHER THAN WRITE
END

FIG. 16

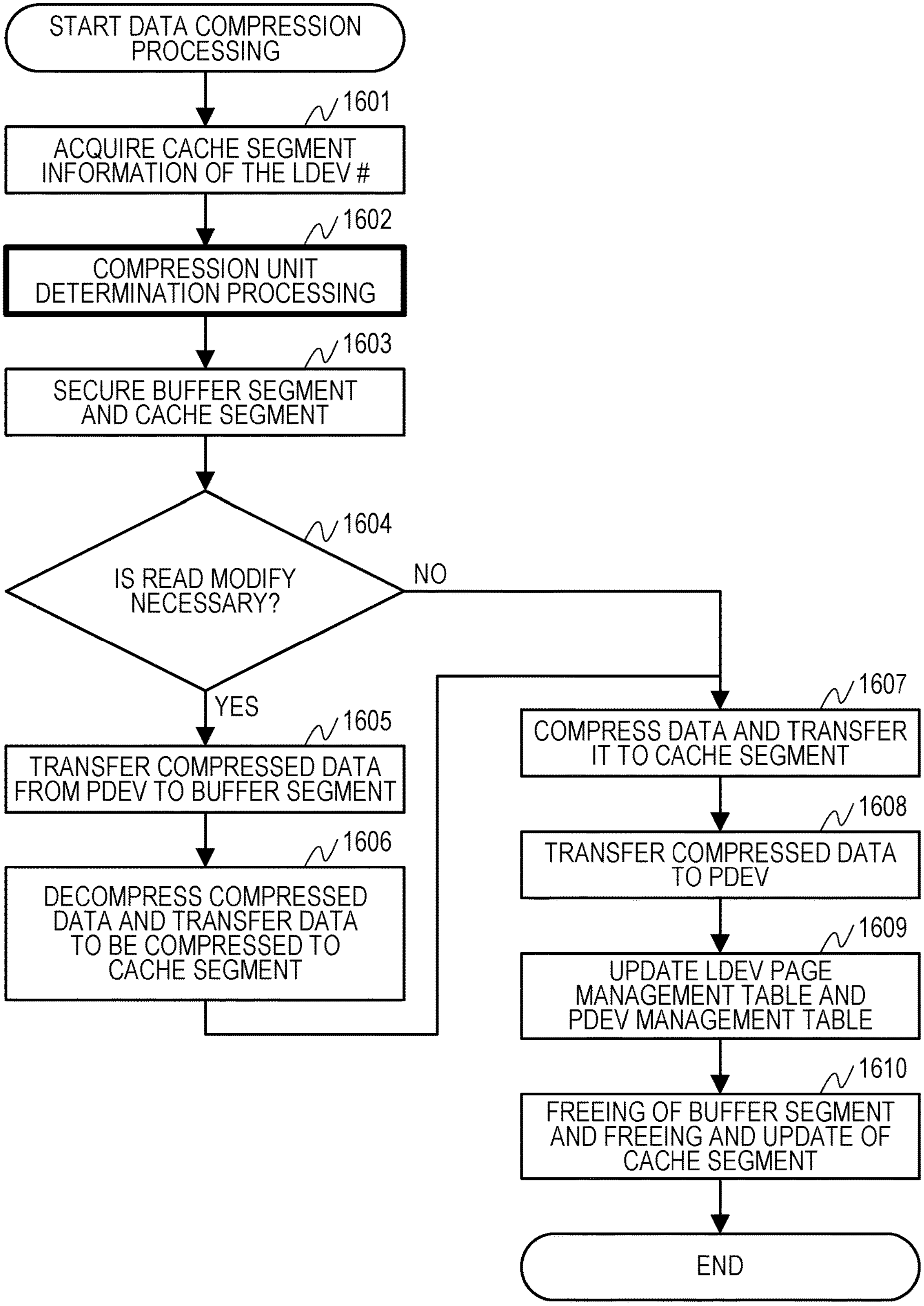

START DATA COMPRESSION PROCESSING
1601
ACQUIRE CACHE SEGMENT INFORMATION OF THE LDEV #
1602
COMPRESSION UNIT DETERMINATION PROCESSING
1603
SECURE BUFFER SEGMENT AND CACHE SEGMENT
1604
IS READ MODIFY NECESSARY?
NO
YES
1605
TRANSFER COMPRESSED DATA FROM PDEV TO BUFFER SEGMENT
1606
DECOMPRESS COMPRESSED DATA AND TRANSFER DATA TO BE COMPRESSED TO CACHE SEGMENT
1607
COMPRESS DATA AND TRANSFER IT TO CACHE SEGMENT
1608
TRANSFER COMPRESSED DATA TO PDEV
1609
UPDATE LDEV PAGE MANAGEMENT TABLE AND PDEV MANAGEMENT TABLE
1610
FREEING OF BUFFER SEGMENT AND FREEING AND UPDATE OF CACHE SEGMENT
END

FIG. 17A

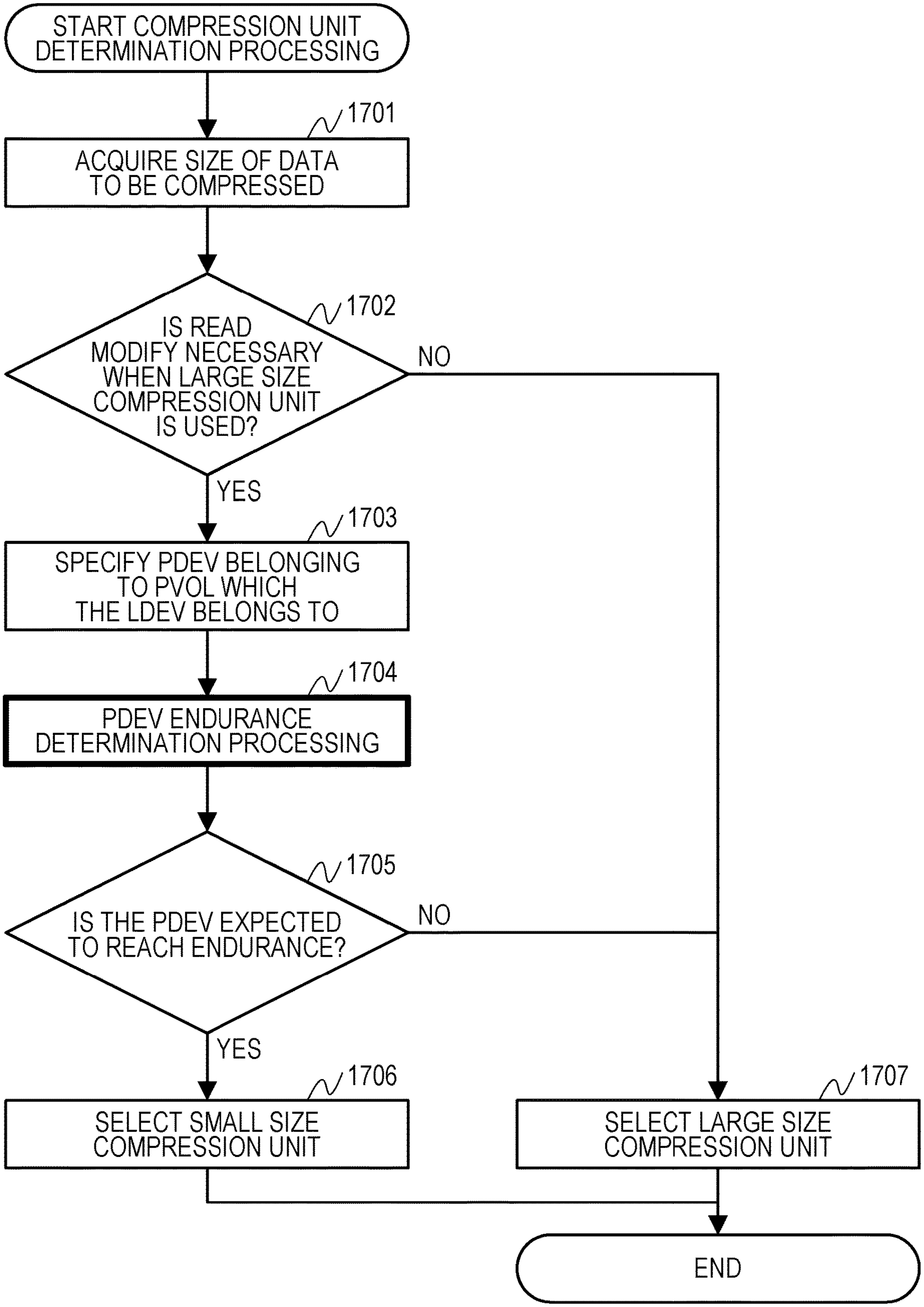

START COMPRESSION UNIT DETERMINATION PROCESSING
1701
ACQUIRE SIZE OF DATA TO BE COMPRESSED
1702
IS READ MODIFY NECESSARY WHEN LARGE SIZE COMPRESSION UNIT IS USED?
NO
YES
1703
SPECIFY PDEV BELONGING TO PVOL WHICH THE LDEV BELONGS TO
1704
PDEV ENDURANCE DETERMINATION PROCESSING
1705
IS THE PDEV EXPECTED TO REACH ENDURANCE?
NO
YES
1706
SELECT SMALL SIZE COMPRESSION UNIT
1707
SELECT LARGE SIZE COMPRESSION UNIT
END

FIG. 17B

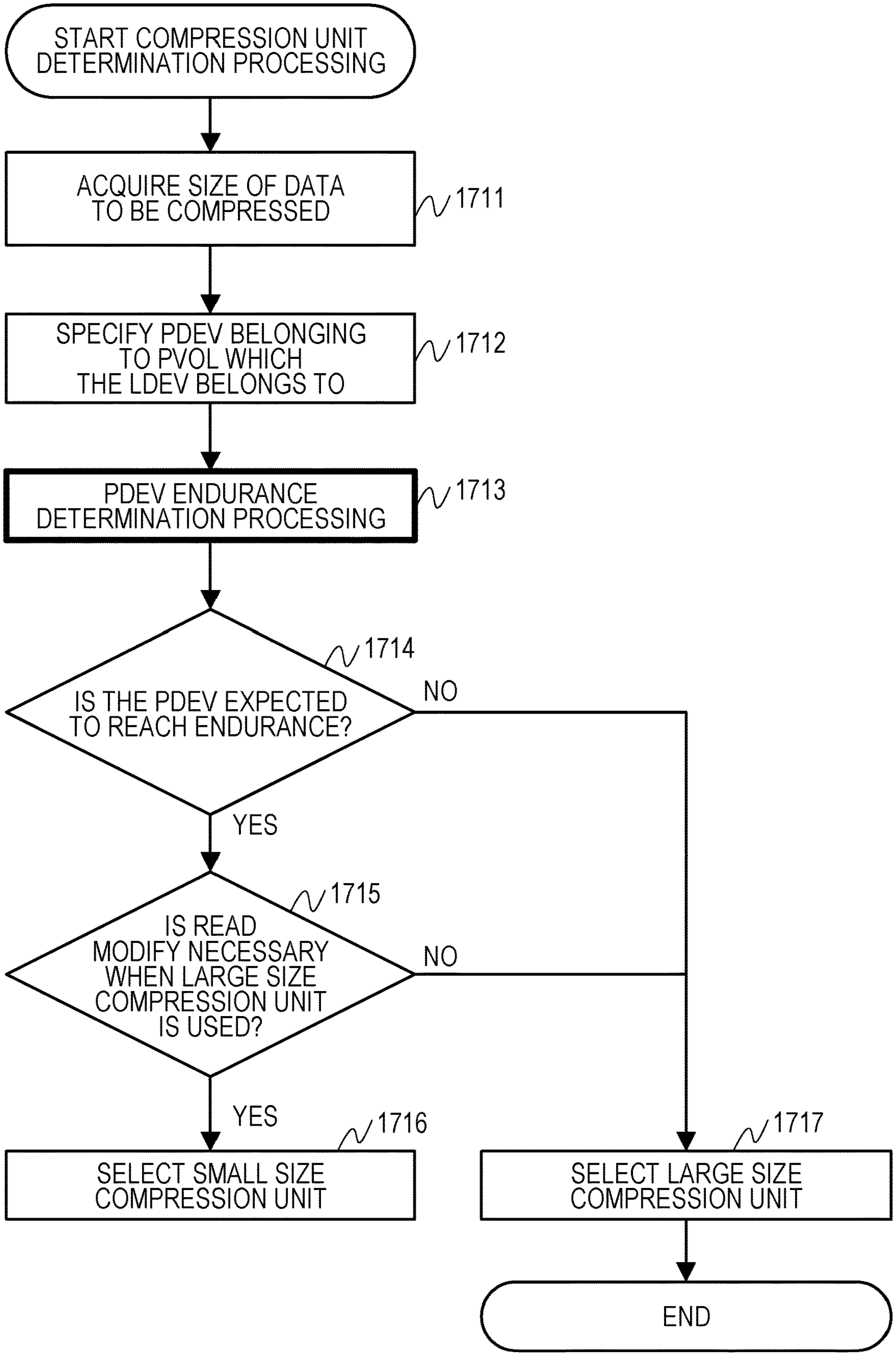

START COMPRESSION UNIT DETERMINATION PROCESSING
ACQUIRE SIZE OF DATA TO BE COMPRESSED
1711
SPECIFY PDEV BELONGING TO PVOL WHICH THE LDEV BELONGS TO
1712
PDEV ENDURANCE DETERMINATION PROCESSING
1713
IS THE PDEV EXPECTED TO REACH ENDURANCE?
1714
NO
YES
IS READ MODIFY NECESSARY WHEN LARGE SIZE COMPRESSION UNIT IS USED?
1715
NO
YES
SELECT SMALL SIZE COMPRESSION UNIT
1716
SELECT LARGE SIZE COMPRESSION UNIT
1717
END

FIG. 18

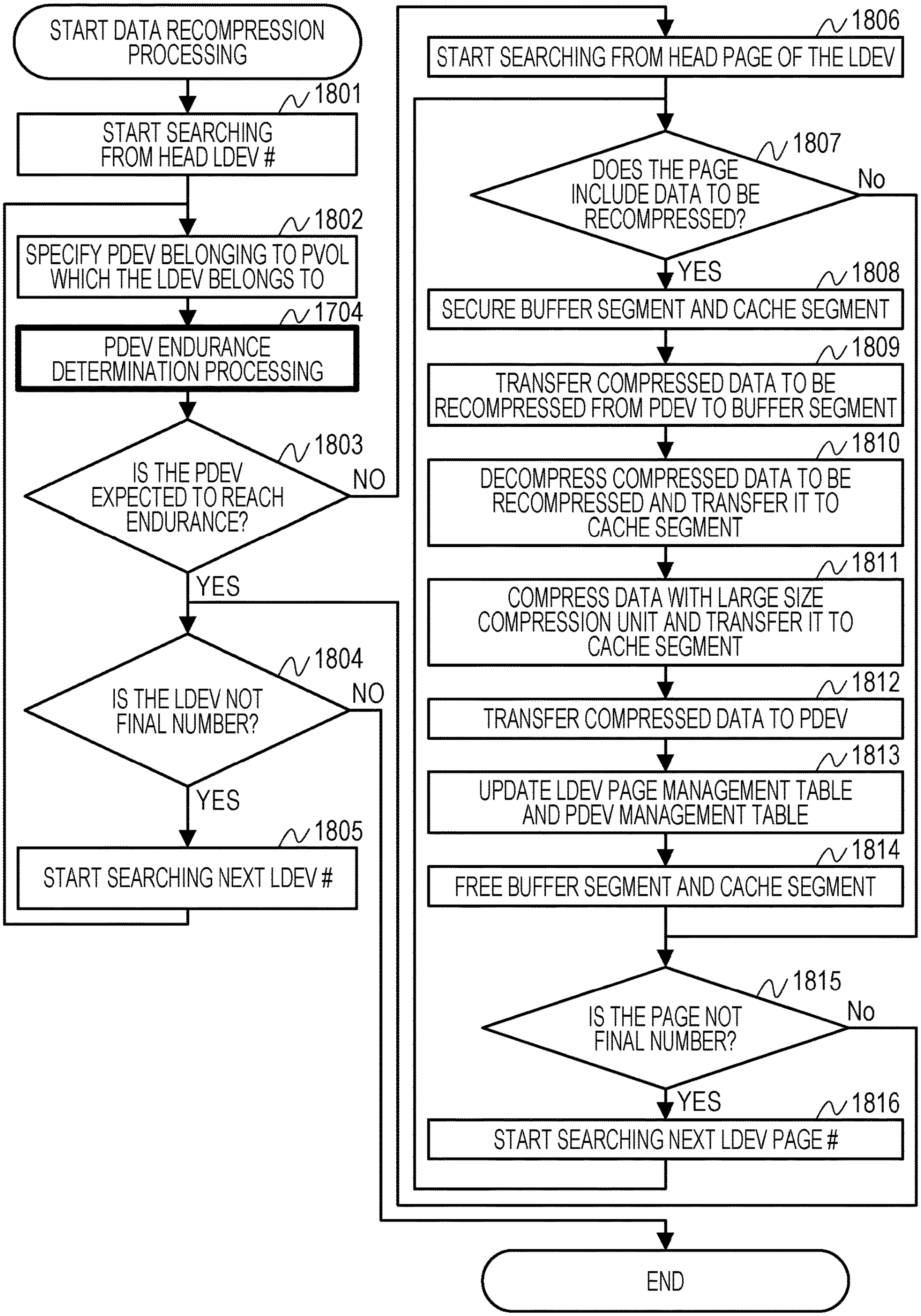
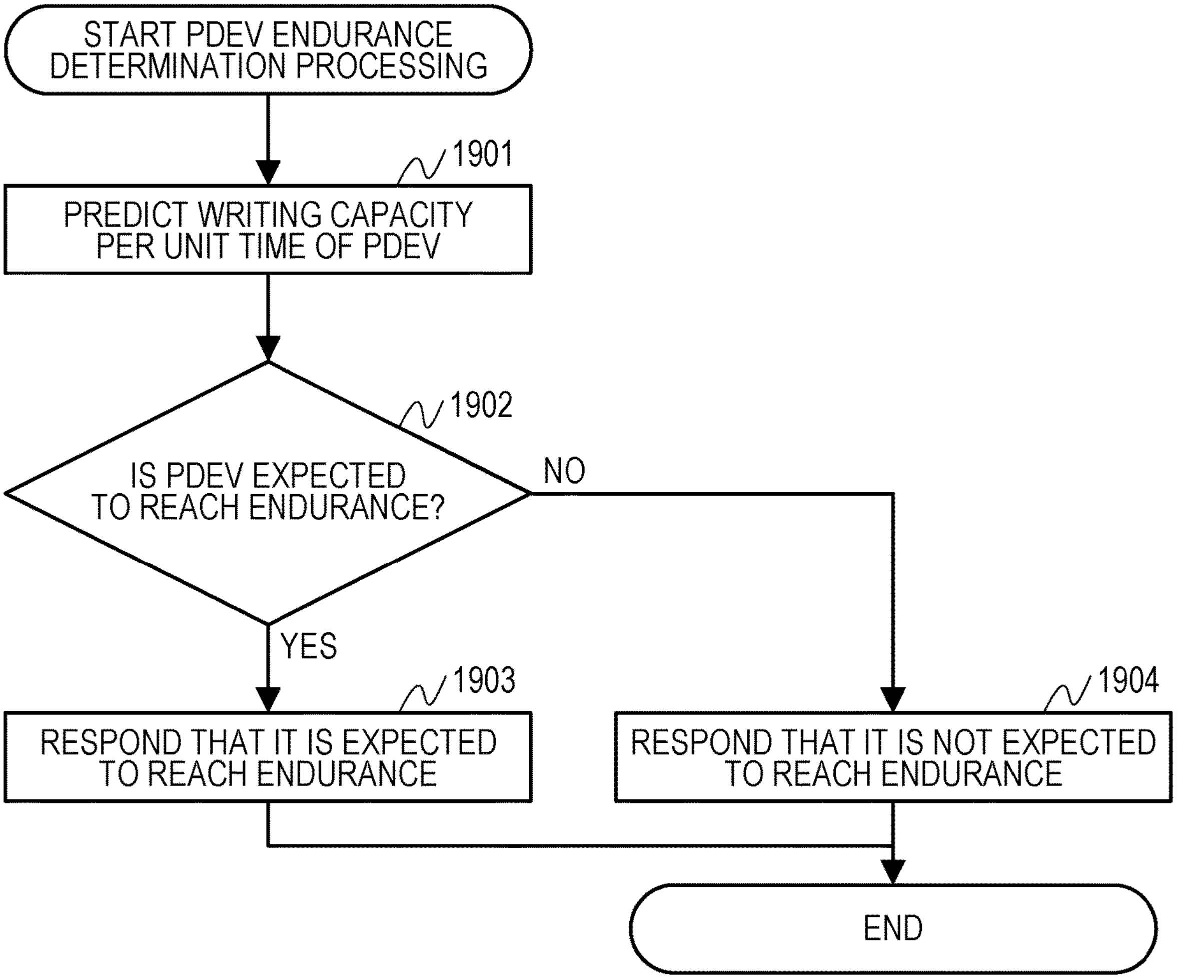

START DATA RECOMPRESSION PROCESSING
1801
START SEARCHING FROM HEAD LDEV #
1802
SPECIFY PDEV BELONGING TO PVOL WHICH THE LDEV BELONGS TO
1704
PDEV ENDURANCE DETERMINATION PROCESSING
1803
IS THE PDEV EXPECTED TO REACH ENDURANCE?
NO
YES
1804
IS THE LDEV NOT FINAL NUMBER?
NO
YES
1805
START SEARCHING NEXT LDEV #
1806
START SEARCHING FROM HEAD PAGE OF THE LDEV
1807
DOES THE PAGE INCLUDE DATA TO BE RECOMPRESSED?
No
YES
1808
SECURE BUFFER SEGMENT AND CACHE SEGMENT
1809
TRANSFER COMPRESSED DATA TO BE RECOMPRESSED FROM PDEV TO BUFFER SEGMENT
1810
DECOMPRESS COMPRESSED DATA TO BE RECOMPRESSED AND TRANSFER IT TO CACHE SEGMENT
1811
COMPRESS DATA WITH LARGE SIZE COMPRESSION UNIT AND TRANSFER IT TO CACHE SEGMENT
1812
TRANSFER COMPRESSED DATA TO PDEV
1813
UPDATE LDEV PAGE MANAGEMENT TABLE AND PDEV MANAGEMENT TABLE
1814
FREE BUFFER SEGMENT AND CACHE SEGMENT
1815
IS THE PAGE NOT FINAL NUMBER?
No
YES
1816
START SEARCHING NEXT LDEV PAGE #
END

FIG. 19


START PDEV ENDURANCE DETERMINATION PROCESSING
1901
PREDICT WRITING CAPACITY PER UNIT TIME OF PDEV
1902
IS PDEV EXPECTED TO REACH ENDURANCE?
NO
YES
1903
RESPOND THAT IT IS EXPECTED TO REACH ENDURANCE
1904
RESPOND THAT IT IS NOT EXPECTED TO REACH ENDURANCE
END

STORAGE SYSTEM

CLAIM OF PRIORITY

The present application claims priority from Japanese patent application JP 2023-152114 filed on Sep. 20, 2023, the content of which is hereby incorporated by reference into this application.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to data compression in a storage system.

2. Description of the Related Art

In recent years, there is an increasing importance of a technology of generating new values by accumulating and analyzing enormous data represented by artificial intelligence (AI). This requires a storage system having sophisticated input/output (I/O) performance in order to analyze accumulated data in addition to accumulating enormous data.

Storage systems having sophisticated I/O performance include an all flash array (AFA) mounted with, in place of a hard disk drive (HDD), a solid state drive (SSD) having overwhelmingly sophisticated I/O performance as compared with the HDD. In general, the AFA is more expensive than a storage system mounted with a known HDD. This is because the price (bit cost) per unit capacity of the SSD is more expensive than that of the HDD. For this reason, the AFA decreases the bit cost by mounting a data reduction function such as compression.

Methods for improving the compression ratio include, as disclosed in U.S. Pat. No. 11,210,032, collectively compressing data and reading and decompressing all.

SUMMARY OF THE INVENTION

In U.S. Pat. No. 11,210,032, the unit of data compression is increased and the compression ratio is improved by collectively compressing data in order of writing. On the other hand, in an existing storage system, when the compression unit is to be extended, it is conceivable to extend the compression unit in units of logical block address (LBA) continuous data. At this time, when the compression unit is larger than the write data unit (host write unit) from a host, read-modify-write is required, but U.S. Pat. No. 11,210,032 does not consider a case of read-modify-write.

This read-modify-write increases the write amount to an SSD mounted in the storage system, thereby decreasing the rewriting endurance of the SSD. This is because the nonvolatile semiconductor device mounted on the SSD has an upper limit on the number of rewrites, and when this upper limit is exceeded, data cannot be read or written. Therefore, when the data compression unit is increased, the rewriting endurance of the SSD decreases.

A storage system of an aspect of the present invention includes: a controller; and one or more storage devices, in which the controller can compress data in different compression units, and collectively compresses data of one or a plurality of consecutive addresses in each compression unit of the different compression units, and the controller receives write data, determines whether read of data stored in the one or more storage devices is necessary for compression of the write data by a first compression unit, determines compression of the write data in the first compression unit in a case where the read is not necessary, and determines compression by the first compression unit or compression by a second compression unit smaller than the first compression unit based on a remaining endurance of rewriting of the one or more storage devices in a case where the read is necessary.

One aspect of the present invention can improve a data reduction ratio and suppress endurance shortening of a storage device having a rewriting endurance.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram illustrating a configuration example of an information system including a storage system;

FIG. **2** is a diagram illustrating a configuration example of a main storage;

FIG. **3** is a diagram illustrating a configuration example of a program area;

FIG. **4** is a diagram illustrating a configuration example of a management information area;

FIG. **5** is a diagram illustrating a configuration example of a PDEV management table;

FIG. **6** is a diagram illustrating a configuration example of a PVOL management table;

FIG. **7** is a diagram illustrating a configuration example of an LDEV management table;

FIG. **8** is a diagram illustrating a configuration example of a PVOL page management table;

FIG. **9** is a diagram illustrating a configuration example of an LDEV page management table;

FIG. **10** is a diagram illustrating a configuration example of a buffer segment management table;

FIG. **11** is a diagram illustrating a configuration example of a cache segment management table;

FIG. **12** is a diagram illustrating a relationship among an LDEV, a PVOL, and a PDEV in a storage system;

FIG. **13** is a diagram illustrating an example of a write data flow accompanied by RMW in a case where a large compression unit is used in the storage system;

FIG. **14** is a diagram illustrating an example of a write data flow in a case where a small compression unit is used in the storage system;

FIG. **15** is a flowchart showing an example of a processing flow based on an I/O request from a host in the storage system;

FIG. **16** is a flowchart showing an example of data compression processing in the storage system;

FIG. **17**A is a flowchart showing an example of processing of determining a data compression unit in the storage system;

FIG. **17**B is a flowchart showing another example of processing of determining a data compression unit in the storage system;

FIG. **18** is a flowchart showing an example of data recompression processing in the storage system; and

FIG. **19** is a flowchart showing an example of processing of determining the endurance of the PDEV in the storage system.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

An example will be described below with reference to the drawings. Note that the example is merely an example for implementing the present invention, and does not limit the technical scope of the present invention.

In the following description, various types of information may be described with an expression of "xxx table", but the various types of information may be expressed with a data structure other than the table. The "xxx table" can be called "xxx information" to be indicative of not depending on the data structure.

In the following description, a number is used as identification information of elements, but another type of identification information (e.g., name or identifier) may be used.

In the following description, a common sign in a reference sign (or a reference sign) may be used when an explanation is made with the same type of elements being not distinguished from one another, and a reference sign (or an element ID) may be used when an explanation is made with the same type of elements being distinguished from one another.

In the following description, the "main storage" may be one or more storage devices including a memory. For example, the main storage may be at least a main storage device among main storage devices (typically a volatile storage device) and auxiliary storage devices (typically a nonvolatile storage device). The storage unit may include at least one of a cache area (e.g., a cache memory or a partial area thereof) and a buffer area (e.g., a buffer memory or a partial area thereof).

In the following description, "PDEV" means a physical storage device, and may typically be a nonvolatile storage device (e.g., an auxiliary storage device). The PDEV may be, for example, a hard disk drive (HDD) or a solid state drive (SSD).

In the following description, "RAID" is an abbreviation of redundant array of independent (or inexpensive) disks. A RAID group includes a plurality of PDEVs, and stores data in accordance with a RAID level associated with the RAID group.

In the following description, "PVOL" may include a plurality of PDEVs, and these PDEVs may constitute a RAID group.

In the following description, "LDEV" means a logical storage device, and includes some or all of "PVOLs", and a host executes an I/O request to the "LDEV".

A "write-once data structure" means a structure in which data after update is stored in a physical position different from that of data before update, and data is updated by changing a reference destination. Since the data size after compression varies depending on the content of the data before compression, in order to increase the efficiency of data reduction, it is necessary to store the data after compression in a PVOL (i.e., a PDEV corresponding to a PVOL) without a gap.

The "write-once data structure" can store, from the head, data after compression from an arbitrary position of the PVOL, and thus it is widely adopted in a storage system having a data reduction function such as compression. In the following description, the storage system has the "write-once data structure", and when an "LDEV" is updated with host write, the data after update is stored in a free area of the PVOL, and the data is updated by switching the reference destination of the data of the "LDEV".

Hereinafter, in a case where processing is described with a "program" as a subject, the subject of the processing may be a storage controller or a processor because the program is executed by a processor (e.g., a central processing unit (CPU)) included in a storage controller, whereby the program appropriately performs predetermined processing using a storage resource (e.g., main storage) and/or a communication interface device (e.g., HCA). The storage controller (CTL) may include a hardware circuit that performs part or the entire of processing. The computer program may be installed from a program source. The program source may be, for example, a program distribution server or a computer-readable storage medium.

In the following description, the "host" is a system that transmits an I/O request to a storage system, and may include an interface device, a storage unit (e.g., a memory), and a processor connected to them. The host system may include one or more host computers. At least one host computer may be a physical computer, and the host system may include a virtual host computer in addition to the physical host computer.

An example of a storage system that collectively compresses data of logical device units or logical device units and continuous logical block addresses (LBAs) will be described below. Note that the example described below does not limit the invention according to the claims, and all combinations of features described in the example are not necessarily essential to the solution of the invention.

In an example of the present description, two or more compression units (large and small) are selectively used. A write amount to an SSD is monitored, and a compression unit is selected based on a rewriting remaining endurance of the SSD. In an example, in a scheduled operating period of an SSD, it is determined whether or not the SSD reaches the rewriting endurance before reaching the scheduled operating period. When the result of the determination indicates that the SSD does not reach the endurance, the data reduction ratio is improved by performing data compression using a large compression unit (first compression unit). On the other hand, for a case where it is determined that the SSD reaches the endurance and read-modify-write is unnecessary, compression is performed using a large compression unit, and on the other hand, for a case where read-modify-write is necessary, compression is performed using a small compression unit (second compression unit). Note that other determination criteria may be used.

The monitoring of the write amount in the present example means statistical monitoring of the write amount. That is, the transition of the write amount is analyzed by continuously monitoring the write amount with respect to the SSD after the operation is started. As a result of this analysis, if a sign that the total write amount (**506** in FIG. **5**) exceeds the maximum writable capacity (**505** in FIG. **5**) allowed in the SSD is observed within the scheduled operating time arbitrarily determined for the SSD is observed, switching of the compression unit is executed and/or application/non-application of recompression processing is switched.

This can improve the data reduction ratio, and can reduce the bit cost of the all flash array (AFA). It is possible to suppress reduction in the endurance of the SSD by reducing read-modify-write associated with increasing of the compression unit with respect to write with the size less than the compression unit from the user, in other words, effectively using the data compression by the second compression unit having a compression unit smaller than the first compression unit. Note that three or more types of compression units having different sizes may be used. The SSD is a typical example of a storage device (also called a storage drive) in which a writable (rewritable) capacity (data amount) is set, and other storage devices having a rewriting endurance can be used in place of the SSD or together with the SSD.

FIG. **1** is a diagram illustrating a configuration example of an information system **101**. The information system **101** includes one or more storage systems **102** and one or more hosts **103**. The storage system **102** includes one or more controllers (CTLs) **104** and one or more PDEV boxes **105**. In the present example, the storage system **102** has a configuration mounted with one CTL **104**, but may have a configuration mounted with a plurality of CTLs to give the CTLs redundancy.

The PDEV box **105** includes one or more PDEVs **110**. In FIG. **1**, the CTL **104** and the PDEV box **105** are directly connected, but may be connected via a network. The CTL **104** includes a processor **106**, the main storage **107**, a front end interface (FE I/F) **108**, and a back end interface (BE I/F) **109**. The number of various elements constituting the CTL **104** may be one or more.

The processor **106** controls the entire CTL **104**, and operates based on a microprogram stored in the main storage **107**. The FE I/F **108** is controlled by the processor **106**, and performs transmission and reception of an I/O request and I/O data from the host **103**. The BE I/F **109** is controlled by the processor **106**, and performs transmission and reception of data and the like with the PDEV **110** via the PDEV box **105**.

FIG. **2** is a diagram illustrating a configuration example of the main storage **107**. In the main storage **107**, a program area **201**, a management information area **202**, a buffer area **203**, and a cache area **204** are secured.

The program area **201** is an area that stores each program for the processor **106** to perform processing. The management information area **202** is an area that is accessed from the processor **106** and stores various management tables. The buffer area **203** and the cache area **204** are areas that temporarily store data at the time of data transfer by the FE I/F **108**, the BE I/F **109**, and the like. Note that the buffer area **203** and the cache area **204** are configured by a plurality of segments (units in which an area is divided), and are managed in units of segments.

FIG. **3** is a diagram illustrating an example of a program stored in the program area **201**.

The program area **201** stores, for example, an I/O program **301**, a segment control program **302**, a data compression/decompression program **303**, a PDEV control program **304**, a PVOL control program **305**, an LDEV control program **306**, and a compression unit control program **307**.

The I/O program **301** executes corresponding processing in accordance with an I/O request from the host **103**. The segment control program **302** is called in a process in which the I/O program **301** performs processing on the I/O request, and secures and releases a buffer segment and a cache segment. The data compression/decompression program **303** is called in a process in which the I/O program **301** performs processing on an I/O request, and compresses data received from the host **103** or decompresses compressed data.

The PDEV control program **304** manages an area and a state of the PDEV **110** and controls transmission and reception of I/O data. The PVOL control program **305** controls an area, a state, and the like of the PVOL. The LDEV control program **306** controls an area, a state, and the like of the LDEV. The compression unit control program **307** controls the unit of compressing data and the like based on the rewriting endurance of the PDEV **110**.

FIG. **4** is a diagram illustrating an example of information stored in the management information area **202**. The management information area **202** stores a PDEV management table **401**, a PVOL management table **402**, an LDEV management table **403**, a PVOL page management table **404**, an LDEV page management table **405**, a buffer segment management table **406**, and a cache segment management table **407**.

The PDEV management table **401** indicates a state of the PDEV **110** and a correspondence relationship with the PVOL of the PDEV **110**. The PVOL management table **402** indicates a state of the PVOL, a correspondence relationship with the PDEV **110** of the PVOL, and a correspondence relationship with the LDEV of the PVOL. The LDEV management table **403** indicates a state of the LDEV and a correspondence relationship between the PVOL and the LDEV.

The PVOL page management table **404** is used to manage a page in which an area of the PVOL is divided by the unit capacity. The LDEV page management table **405** is used to manage a page in which an area of the LDEV is divided by the unit capacity. The buffer segment management table **406** is used to manage the segment of the buffer area **203**. The cache segment management table **407** is used to manage the segment of the cache area **204**.

FIG. **5** is a diagram illustrating a configuration example of a PDEV management table **401**.

The PDEV management table **401** includes columns of a PDEV #**501**, a capacity **502**, a state **503**, a belonging PVOL #**504**, a writable capacity **505**, a total write capacity **506**, a scheduled operating time **507**, and an operating time **508**.

The PDEV #**501** indicates an identifier of the PDEV **110**. The capacity **502** indicates a capacity with which data of the PDEV **110** can be stored. The state **503** indicates a state in which the PDEV **110** is normal or abnormal (failure or reaching the rewriting endurance). The belonging PVOL #**504** indicates to which PVOL the PDEV **110** belongs. The writable capacity **505** indicates a capacity (data amount) that can be written to the PDEV **110**. Each cell constituting the SSD can write the data again by clearing written data (deleting data to make a free area), but a physical upper limit exists in the number of executable times of this operation.

Therefore, a value in which a design capacity of the SSD is multiplied by the number of executable times of this clear/write or a value similar thereto is set as the writable capacity (data amount) as a product endurance. The total write capacity **506** indicates the total capacity having been written to the PDEV **110** so far, in other words, it can also be defined as the total write amount starting from the operation start of the SSD. The scheduled operating time **507** indicates the total time during which the PDEV **110** is scheduled to operate. The operating time **508** indicates the total time during which the PDEV **110** operated.

FIG. **6** is a diagram illustrating a configuration example of a PVOL management table **402**. The PVOL management table **402** includes columns of a PVOL #**601**, a used capacity/total capacity **602**, a recompressible data ratio **603**, a belonging LDEV #**604**, a state **605**, a redundant configuration **606**, a belonging PDEV **607**, and a PVOL page management table storage address **608**.

The PVOL #**601** indicates an identifier of the PVOL. The used capacity/total capacity **602** indicates, of the PVOL, the used capacity in which data is already stored and the total capacity including the used capacity and the capacity in which data is not yet stored. The recompressible data ratio **603** indicates a ratio of data in which the compression ratio of the data can be improved by recompressing the data among the data stored in the PVOL.

The belonging LDEV #**604** indicates an identifier (LDEV #) of the LDEV clipped from the PVOL. The state **605** indicates whether or not the state of the PVOL is normal. The redundant configuration **606** indicates an RIAD level of the PDEV **110** constituting the PVOL. The belonging PDEV **607** indicates an identifier (PDEV #) of the PDEV **110** constituting the PVOL. The PVOL page management table storage address **608** indicates an address on the main storage **107** that stores a table for managing a page in which the PVOL is divided by the unit capacity.

FIG. **7** is a diagram illustrating a configuration example of an LDEV management table **403**. The LDEV management table **403** includes an LDEV #**701**, a capacity **702**, a state **703**, a belonging PVOL #**704**, and an LDEV page management table storage address **705**.

The LDEV #**701** indicates an identifier of the LDEV. The capacity **702** indicates a capacity with which data can be stored in the LDEV. The state **703** indicates whether or not I/O to the LDEV can be normally performed. The belonging PVOL #**704** indicates the PVOL # to which the LDVE belongs. The LDEV page management table storage address **705** indicates an address on the main storage **107** that stores a table for managing a page in which the LDEV is divided by the unit capacity.

FIG. **8** is a diagram illustrating a configuration example of a PVOL page management table **404**. The PVOL page management table **404** includes a PVOL page #**801**, a state **802**, a valid LDEV page count **803**, an invalid LDEV page count **804**, and an in-PVOL page next write start address **805**.

The PVOL page #**801** indicates an identifier of the PVOL page. The state **802** is a state of the PVOL page, where open indicates being written (a state where data is stored partway in the PVOL page), close indicates having been written, and free indicates being not used.

The valid LDEV page count **803** indicates the number of LDEV pages storing valid data allocated to the PVOL page. The invalid LDEV page count **804** indicates the number of LDEV pages storing invalid data allocated to the PVOL page. One or more LDEV pages are allocated to one PVOL page, and in this example, a plurality of LDEV pages are allocated. The in-PVOL page next write start address **805** indicates a head address of an unwritten area from the head of the PVOL page in the PVOL page in which the state **802** is open.

FIG. **9** is a diagram illustrating a configuration example of an LDEV page management table **405**. The LDEV page management table **405** includes an LDEV page #**901**, a state **902**, an allocation destination PVOL page #**903**, an in-PVOL page start address **904**, a compression unit (LDEV page count) **905**, a compressed size **906**, and an in-compression data page #**907**.

The LDEV page #**901** indicates an identifier of the LDEV page. The state **902** indicates whether or not the LDEV page is allocated to the PVOL page. The allocation destination PVOL page #**903** indicates a PVOL page # to which the LDEV page is allocated. The in-PVOL page start address **904** indicates a start address in the PVOL page storing compressed data including the LDEV page.

The compression unit (LDEV page count) **905** indicates a compression unit (the number of LDEV pages collectively compressed) used when data is compressed. The compressed size **906** indicates the size of compressed data including the LDEV page. The in-compression data page #**907** indicates an identifier for specifying the LDEV page among the compressed data including the LDEV page.

FIG. **10** is a diagram illustrating a configuration example of a buffer segment management table **406**. The buffer segment management table **406** includes a segment #**1001** and a state **1002**. The segment #**1001** indicates an identifier of the buffer segment. The state **1002** indicates whether or not the buffer segment is secured (lock, free).

FIG. **11** is a diagram illustrating a configuration example of s cache segment management table **407**. The cache segment management table **407** includes a segment #**1101**, a state **1102**, a data type **1103**, an allocation destination LDEV #**1104**, and an LDEV page #**1105**.

The segment #**1101** indicates an identifier of the cache segment. The state **1102** indicates a state of the cache segment, where clean indicates that the PDEV has stored the latest data, dirty indicates that the data on the cache segment is the latest, and free indicates being not used.

The data type **1103** indicates whether or not the data stored in the cache segment is compressed or uncompressed. The allocation destination LDEV #**1104** indicates the LDEV # to which the data stored in the cache segment belongs. The LDEV page #**1105** indicates the LDEV page # in the LDEV # to which the data stored in the cache segment belongs.

FIG. **12** is a diagram illustrating the correspondence relationship among the host **103**, the LDEV, the PVOL, the PDEV **110**, the LDEV page, and the PVOL page.

One or more LDEVs **1201** exist in the storage system **102** and provide an address space accessible from the host **103**. A PVOL **1202** is a pool (address space) including one or more PDEVs **110**. The LDEV **1201** includes one or more LDEV pages **1203**. The PVOL **1202** includes one or more PVOL pages **1204**. The PDEV **110** is divided into one or more areas **1205**, and each area **1205** corresponds to one PVOL page **1204**.

The host **103** is connected to one or more LDEVs **1201** (**1206**). The LDEV page **1203** is allocated to one or more PVOL pages **1204** (**1207**). The PVOL page **1204** is allocated to a divided area **1205** of one or more PDEVs **110** (**1208**).

An embodiment of the present description selectively uses a plurality of compression units having different sizes for write data from the host **103**. An example of a write processing sequence using compression units of different sizes will be described below. First, FIG. **13** illustrates an example of the write processing sequence accompanied by read-modify for compression processing using a large compression unit in the storage system **102**.

In order to describe the write processing sequence of data, this figure describes the constituent elements of the information system **101** partially omitted. The write data size from the host **103** is equivalent to the LDEV page **1203**, and the compression unit is described as four LDEV pages **1203**. The write data size is a data unit written from the host **103**. The write data unit, that is, the address of the LDEV page is the LBA. Note that one LBA address may include a plurality of LBA pages.

In the following description, in the storage system **104**, it is assumed that four items of data before compression of the LDEV page **1203** included in one item of compression data are mapped with fixed addresses so as to be LBA continuous. Due to this, the implementation of a program of address conversion does not become complicated and the size of the metadata used for address conversion can be reduced as compared with that corresponding to LBA discontinuity. Note that the four items of data before compression of the LDEV page **1203** need not be fixed as long as they are LBA continuous.

The host **103** writes data **1301** to the CTL **104** (**1302**). The write data is stored in the cache area **204**. In order to compress the data, the CTL **104** reads compression data-before update **1303** including the data from the PDEV **110**

(**1304**). The CTL **104** stores the compression data-before update **1303** in the buffer area **203** and then decompresses it (**1305**).

The CTL **104** temporarily stores decompressed data **1306** in the buffer area **203**, and transfers (read-modify) data other than the data **1301** to the cache area **204** (**1307**, **1308**, and **1309**). The CTL **104** compresses data **1310** after read-modify (**1311**). The CTL **104** temporarily stores compression data-after update **1312** in the cache area **204**, and then transfers it to the PDEV **110** (**1313**). In this manner, in a case where the write data size is smaller than the compression unit, the read-modify-write occurs.

FIG. **14** illustrates an example of a write processing sequence using a compression unit smaller than the compression unit illustrated in FIG. **13** in the storage system **0104**. In order to describe the write processing sequence of data, FIG. **14** describes the constituent elements of the information system **101** partially omitted. In the write processing sequence described with reference to FIG. **14**, a case in which the write data size from the host **103** is equivalent to that of the LDEV page **1203**, and one LDEV page **1203** is used as the compression unit is described.

The host **103** writes data **1401** to the CTL **104** (**1402**). The write data is stored in the cache area **204** and compressed (**1403**). Thereafter, compression data-after update **1404** is transferred to the PDEV **110** (**1405**).

In this manner, by compressing the write data in the compression unit selected from a plurality of compression units, it is possible to reduce the write amount to the PDEV **110** without requiring read-modify of compression data-before update.

FIG. **15** is a flowchart showing an example of the flow in which the storage system **102** performs processing on an I/O request received from the host **103**.

After receiving the I/O request from the host **103**, the I/O program **301** of the CTL **104** analyzes the I/O request to clarify the I/O type (read, write, or others) and the like (**1501**).

By using the I/O type clarified in processing **1501** of analysis of the I/O request from the host, the I/O program **301** determines whether or not the I/O type is write (**1502**). When the I/O type is write (**1503**: Yes), the process proceeds to processing **1504** (A). On the other hand, when the I/O type is not write (**1503**: No), the process proceeds to processing **1510** (B).

(A)

After the segment control program **302** secures the cache segment, the I/O program **301** receives write data from the host **103** and registers the data in the cache (**1503**).

The I/O program **301** notifies the host **103** of completion of write (**1504**).

The I/O program **301** calls data compression processing in order to compress data (**1505**).

The I/O program **301** calls data recompression processing in order to improve the data compression ratio in the storage system **102** (**1506**).

In order to eliminate fragmentation in the PVOL page caused by log writing, the I/O program **301** calls garbage collection processing, executes the processing, and then ends the processing (**1507**).

(B)

After executing the processing based on the I/O request, the I/O program **301** ends the processing (**1508**). Here, since the processing is not affected by the present invention, detailed processing will not be described.

FIG. **16** is a flowchart showing an example of the flow of the data compression processing **1505** called from the flowchart described in FIG. **15**.

With reference to the cache segment management table **407**, the data compression/decompression program **303** acquires state information of a cache segment related to a write destination LDEV of the write data received from the host **103** (**1601**).

The data compression/decompression program **303** calls compression unit determination processing and receives a determination result of the compression unit (**1602**). In the example described below, it is assumed that one compression unit is selected from two compression units having different sizes. For example, a large compression unit is a 4-page LDEV page, and a small compression unit is a 1-page LDEV page. Details of the compression unit determination processing described later.

The segment control program **302** secures a free buffer segment and a free cache segment (**1603**).

The data compression/decompression program **303** determines whether or not read-modify is necessary based on the results of processing **1601** of acquiring the cache segment information of the LDEV # and the compression unit determination processing **1602** (**1604**).

When all data necessary for compression in the determined compression unit is included in the write data, read-modify is unnecessary. When read-modify is unnecessary, compressed old write data is discarded without being updated, and compression data including new write data is stored in the free area of the PVOL. When the determined compression unit is a small compression unit, read-modify is unnecessary. When the determined compression unit is a large compression unit, in a case where part of data of compression target is stored in the PDEV **110**, read-modify is necessary, and otherwise, read-modify is unnecessary.

When read-modify is necessary (**1604**: Yes), the flow proceeds to processing **1605** (A). On the other hand, when read-modify is unnecessary (**1604**: No), the flow proceeds to processing **1607** (B).

(A)

The PDEV control program **304** transfers the compressed data including the data of read-modify target from the PDEV **110** to the buffer segment secured in processing **1603** (**1605**).

The data compression/decompression program **303** decompresses the compressed data transferred in processing **1605**, and transfers only the data of a target of compression to the cache segment secured in processing **1603** (**1606**). Thereafter, the process proceeds to processing **1607** (B).

(B)

The data compression/decompression program **303** compresses the data on the cache segment and transfers the compressed data to the cache segment (**1607**). At this time, when read-modify is performed in addition to host write data, the data of read-modify target is compressed together. The result of processing **1602** is used as a compression unit.

The PDEV control program **304** transfers the data compressed in processing **1607** from the cache segment to the PDEV **110** (**1608**).

The LDEV control program **306** updates information (**0902** to **0907**) regarding the data storage position of the LDEV page management table **405** for the LDEV page corresponding to the data transferred to the PDEV **110** in processing **1608**. The PDEV control program **304** updates the PDEV management table **401** for the total write capacity **506** and the operating time **508** of the PDEV **110** (**1609**).

The segment control program **302** releases the buffer segment secured in processing **1603**. The cache segment management table **407** is updated, the state of the cache segment corresponding to the data stored in the PDEV **110** in processing **1608** is changed to clean, and the cache segment secured in other processing **1603** is released (**1610**). Thereafter, the processing ends.

FIG. **17** is a flowchart showing an example of the flow of the compression unit determination processing **1602** called from the flowchart described in FIG. **16**. In the following description, it is assumed that one compression unit is selected from two compression units having different sizes. For example, a large compression unit is a 4-page LDEV page, and a small compression unit is a 1-page LDEV page.

The compression unit control program **307** acquires the size of compression target data (**1701**).

The compression unit control program **307** determines whether or not read-modify becomes necessary when a large size compression unit is used based on the information acquired in processing **1701** (**1702**). The determination method is the same as described above. That is, when a part of data necessary for compression in a compression unit of a large size is stored in the PDEV **110**, read-modify is necessary, and otherwise, read-modify is unnecessary.

When read-modify is necessary (**1702**: Yes), the flow proceeds to processing **1703** (A). On the other hand, when read-modify is unnecessary (**1702**: No), the flow proceeds to processing **1707** (C).

(A)

With reference to the LDEV management table **403** and the PVOL management table **402**, the compression unit control program **307** specifies the PDEV **110** belonging to the PVOL to which the write destination LDEV of the compression target data belongs (**1703**). In general, there are a plurality of PDEVs **110** belonging to the PVOL.

The compression unit control program **307** calls PDEV endurance determination processing **1704**. The PDEV endurance can be known in several methods. As described later, with reference to the PDEV management table **401**, it can also be estimated from the information of the writable capacity **505**, the total write capacity **506**, the scheduled operating time **507**, and the operating time **508**. Alternatively, information on the endurance of the PDEV **110** can be obtained from each PDEV **110**.

Based on the result of processing **1704**, the compression unit control program **307** determines whether or not each of the PDEVs **110** specified in processing **1703** is expected to reach the rewriting endurance within operating scheduled time (**1705**).

When any of the PDEVs is expected to reach the rewriting endurance within the operating scheduled time (**1705**: Yes), the flow proceeds to processing **1706** (B). On the other hand, when any of the PDEVs is expected not to reach the rewriting endurance within the operating scheduled time (**1705**: No), the flow proceeds to processing **1707** (C).

By referring to the rewriting remaining endurance and the preset operating scheduled time, it is possible to reduce the possibility that any PDEV reaches the rewriting endurance within the operating scheduled time. Note that it is not necessary to refer to the operating scheduled time. For example, a determination result as to whether or not the rewriting remaining endurance has reached a preset threshold may be referred to. This point is similar to determination in other steps referring to the operating scheduled time and the rewriting remaining endurance.

(B)

The compression unit control program **307** selects a compression unit of a small size and makes a response of this to the processing of the caller (**1706**). In other words, it is given to the data compression/decompression program **303** that the selected compression unit is a small size, and a compression unit of a small size close to the compression target data size is applied, and therefore it is determined that read-modify is unnecessary (**1604**). Thereafter, the processing is ended. Due to this, in a situation where the rewriting endurance of the PDEV is approaching, it is possible to avoid an increase in the write data amount by read-modify accompanying the application of the large size compression unit, and it is possible to reduce the possibility that the actual operating time of the PDEV **110** becomes shorter than the scheduled operating time.

(C)

The compression unit control program **307** selects a compression unit of a large size and makes a response of this to the processing of the caller (**1707**). In other words, the result of selecting the large size compression unit is given to the data compression/decompression program **303**, and it is determined that read-modify is necessary (**1604**). This makes it possible to more efficiently use the storage area of the PDEV **110** by applying the large size compression unit under an environment where there is a margin for the rewriting endurance of the PDEV. Thereafter, the processing is ended.

Note that in the present example, the compression units to be used are described as two (large and small), but three or more compression units may be provided, and these may be controlled to be selectively used depending on the remaining amount of the rewriting endurance of the PDEV **110**. For example, the sizes of the four compression units may be 1 LDEV page, 2 LDEV pages, 4 LDEV pages, and 8 LDEV pages. Each size of the compression units may be a power of 2.

For example, the compression unit control program **307** determines whether any of the corresponding PDEVs **110** reaches the rewriting endurance within the operating scheduled time sequentially from the largest compression unit. The largest compression unit in which all the corresponding PDEVs **110** do not reach the rewriting endurance within the operating scheduled time is selected.

In the example shown in FIG. **17**A, it is determined whether or not read-modify should be performed when a large size compression unit is applied (**1702**), and thereafter the PDEV remaining endurance determination (**1704**) is executed. This determination order can be interchanged. That is, the PDEV remaining endurance determination may be executed first, and then determination of application/non-application of read-modify may be performed.

FIG. **17**B shows a flowchart of the other example. Steps **1711** and **1712** are similar to steps **1701** and **1703** in FIG. **17**A. In this processing method, after the PDEV endurance determination processing (**1713**) and the PDEV remaining endurance determination (**1714**) are executed, determination (**1715**) of application/non-application of read-modify is executed. In accordance with the determination results of the PDEV remaining endurance determination (**1714**) and the determination of application/non-application of read-modify (**1715**), a small size compression unit is selected (**1716**) or a large size compression unit is selected (**1717**). The determination result and the selection of the compression unit size are similar to the processing of FIG. **17**A.

Compression efficiency (how much data can be reduced) qualitatively increases as the compression unit increases. Therefore, a compression unit 32 KB is statistically superior to 8 KB in terms of compression efficiency. However, when individual write data is actually seen, 32 KB is superior to 8 KB as an expected value but it is not reliable, regarding a point as to whether 32 KB compression is superior to 8 KB compression in the compression efficiency for the result after compression.

In the processing method shown in FIG. **17**A, the large size compression unit is applied to data in which use of read-modify is inappropriate, and the large size compression unit in which the compression result is likely to be excellent is applied if the PDEV has a margin from the viewpoint of the remaining endurance even if data can be applied with read-modify. That is, it is an approach that makes it possible to also manage the remaining endurance while giving priority to a high compression efficiency. On the other hand, since the processing method shown in FIG. **17**B is an approach of first performing the remaining endurance determination of the PDEV, priority is given to the remaining endurance management, and then the compression efficiency is appropriately managed.

FIG. **18** is a flowchart showing an example of the flow of the data recompression processing **1506** called from the flowchart described in FIG. **15**. Note that the data recompression processing may be periodically executed. The data recompression processing enables efficient use of the storage area while suppressing the possibility of replacement before the operating scheduled time of the PDEV.

With reference to the LDEV management table **403**, the compression unit control program **307** starts searching for a data recompression target LDEV in order from the head LDEV #**701** (**1801**). Thereafter, the process proceeds to processing **1802** (A).

(A)

With reference to the LDEV management table **403** and the PVOL management table **402**, the compression unit control program **307** specifies the PDEV **110** belonging to the LDEV #**701** being processed (**1802**).

The compression unit control program **307** calls PDEV endurance determination processing **1704**.

Based on the result of processing **1704**, the compression unit control program **307** determines whether or not each of the PDEVs **110** specified in processing **1802** is expected to reach the rewriting endurance within operating scheduled time (**1803**). When any of the PDEVs is expected to reach the rewriting endurance within the operating scheduled time (**1803**: Yes), the flow proceeds to processing **1804** (B). On the other hand, when any of the PDEVs is expected not to reach the rewriting endurance within the operating scheduled time (**1803**: No), the flow proceeds to processing **1806** (D).

(B)

With reference to the LDEV management table **403**, the compression unit control program **307** determines whether or not the LDEV #**701** currently being searched is not a final number (**1804**). When the LDEV #**701** currently being searched is not the final number (**1804**: Yes), the process proceeds to processing **1805** (C). On the other hand, when the LDEV #**701** currently being searched is the final number (**1804**: No), the processing is ended.

(C)

With reference to the LDEV management table **403**, the compression unit control program **307** determines a number to be searched next to the LDEV #**701** currently being searched, and starts searching (**1805**). Thereafter, the process proceeds to processing **1802** (A).

(D)

With reference to the LDEV page management table **405** corresponding to the LDEV currently being searched, the compression unit control program **307** starts searching for an LDEV page for which data is recompressed in order from the head LDEV page #**901** (**1806**). Thereafter, the process proceeds to processing **1807** (E).

(E)

The compression unit control program **307** determines whether or not recompressible data is included in the LDEV page #**901** currently being searched (**1807**). Note that the recompressible data can be determined based on whether or not data compressed in a compression unit smaller than the compression unit of the maximum size among selectable compression units is included.

The determination as to whether or not recompression is possible is made for each LDEV page count for a large size compression unit including the LDEV page #**901** being searched. For example, when the large size compression unit is four LDEV pages, determination is made for four consecutive LBA pages whose head is the LDEV page #**901** being searched.

As a result of the determination, when the recompressible data is included in the LDEV page (**1807**: Yes), the flow proceeds to processing **1808** (F). On the other hand, when the recompressible data is not included in the LDEV page (**1807**: No), the flow proceeds to processing **1815** (G).

(F)

The segment control program **302** secures a free buffer segment and a free cache segment (**1808**).

The PDEV control program **304** transfers the compressed data of a recompression target from the PDEV **110** to the buffer segment secured in processing **1808** (**1809**).

The CTL **104** decompresses the compressed data of the recompression target and transfers it to the cache segment (**1810**).

The compression unit control program **307** compresses the data decompressed in processing **1810** using the large size compression unit and transfers it to the cache segment (**1811**).

The PDEV control program **304** transfers the data compressed in processing **1811** to the PDEV **110** (**1812**).

The LDEV control program **306** updates information (**0902** to **0907**) regarding the data storage position of the LDEV page management table **405** for the LDEV page corresponding to the data transferred to the PDEV **110** in processing **1812**. The PDEV control program **304** updates the PDEV management table **401** for the total write capacity **506** and the operating time **508** of the PDEV **110** (**1813**).

The segment control program **302** releases the buffer segment and the cache segment secured in processing **1808** (**1814**). Thereafter, the process proceeds to processing **1815** (G).

(G)

With reference to the LDEV page management table **405** corresponding to the LDEV currently being searched, the compression unit control program **307** determines whether or not the LDEV page is the final number (**1815**). Note that the determination here is made for each LDEV page count for a large size compression unit including the LDEV page #**901** being searched. For example, when the large size compression unit is four LDEV pages, determination is made for four consecutive LBA pages whose head is the LDEV page #**901** being searched. When the LDEV page of the determination target includes the page of the final number (**1815**: Yes), the process proceeds to processing **1816** (H). On the other hand, when the LDEV page of the determination target does not include the page of the final number (**1815**: No), the process proceeds to processing **1804** (B).

(H)

With reference to the LDEV page management table **405** corresponding to the LDEV currently being searched, the compression unit control program **307** determines a number to be searched next to the LDEV page #**901** currently being searched, and starts searching (**1816**). Note that the recompression processing is executed for each LDEV page count for a large size compression unit including the LDEV page #**901** currently being searched. For example, when the large size compression unit is four LDEV pages, processing is performed for four consecutive LBA pages whose head is the LDEV page #**901** being searched. In this case, the number to be searched next is a number in which 4 is added to the LDEV page #**901** currently being searched. Thereafter the flow proceeds to processing **1807** (E).

The recompression processing can perform recompression while reducing the possibility of reaching the rewriting endurance within the operating scheduled time of the PDEV, and can improve the use efficiency of the storage area. Note that it is not necessary to refer to the operating scheduled time for determination on the presence or absence of recompression execution. For example, a determination result as to whether or not the rewriting remaining endurance has reached a preset threshold may be referred to. In this manner, the compression data of the recompression target can be determined based on the remaining endurance of the PDEV.

FIG. **19** is a flowchart showing an example of the flow of the PDEV endurance determination processing **1704** called from the flowchart described in FIGS. **17**A, **17**B, and **18**.

With reference to the PDEV management table **401**, the compression unit control program **307** calculates remaining operating scheduled time (obtained by subtracting the operating time **508** from the scheduled operating time **507**) of the target PDEV. The writing amount per operating time is calculated with reference to the writable capacity **505** (**1901**).

The compression unit control program **307** determines whether or not the PDEV is expected to exceed the writable capacity **505** during the scheduled operating time **507** (whether or not the PDEV is expected to reach the endurance) based on the calculation result of processing **1901** (**1902**). If the PDEV is expected to reach the endurance (**1902**: Yes), the compression unit control program **307** responds that it is expected to reach the endurance (**1903**). On the other hand, if the PDEV is expected not to reach the endurance (**1903**: No), the compression unit control program **307** respond that it is expected not to reach the endurance (**1904**). Thereafter, the processing is ended.

Note that here, the write amount is used as an index for determining the endurance of the PDEV, but other means such as using an indicator value related to the endurance inherent to the PDEV may be used.

As described above, according to an example of the present description, it is possible to reduce the SSD maintenance and replacement frequency without increasing the ratio of SSDs that reach the rewriting endurance during the operating period of the storage system and to improve the data reduction ratio.

Note that the present invention is not limited to the example described above, and includes various modifications. For example, the above-described example has been described in detail for easy understanding of the present invention, and is not necessarily limited to those having all the described configurations. A part of the configuration of a certain example can be replaced by the configuration of another example, and the configuration of another example can be added to the configuration of a certain example. A part of the configuration of each example can be added to, deleted from, or replaced by another configuration.

Some or all of the above-described configurations, functions, processing units, and the like may be implemented by hardware, for example, by designing with an integrated circuit. The above configurations, functions, and the like may be implemented by software by a processor interpreting and executing a program that implements each function. Information such as a program, a table, and a file for implementing each function can be stored in a memory, a recording device such as a hard disk and a solid state drive (SSD), or a recording medium such as an IC card and an SD card.

The control lines and the information lines indicate what is considered to be necessary for the description, and do not necessarily indicate all the control lines and the information lines on the product. In practice, almost all the configurations may be considered to be connected to one another.

What is claimed is:

1. A storage system comprising:

a controller; and

one or more storage devices, wherein

the controller can compress data in different compression units, and collectively compresses data of one or a plurality of consecutive addresses in each compression unit of the different compression units, and

the controller

receives write data,

determines whether read of data stored in the one or more storage devices is necessary for compression of the write data by a first compression unit,

determines compression of the write data in the first compression unit in a case where the read is not necessary, and

determines compression by the first compression unit or compression by a second compression unit smaller than the first compression unit based on a remaining endurance of rewriting of the one or more storage devices in a case where the read is necessary.

2. The storage system according to claim **1**, wherein

an address range in each compression unit of the different compression units is fixed.

3. The storage system according to claim **1**, wherein

the controller determines compression in a second compression unit smaller than the first compression unit when determining that any storage device of the one or more storage devices reaches a rewriting endurance within a preset scheduled operating time.

4. The storage system according to claim **1**, wherein

the second compression unit matches a write unit of the write data to the storage system.

5. The storage system according to claim **1**, wherein

the controller determines a presence or absence of execution of recompression processing of data compressed in the second compression unit stored in the one or more storage devices based on a remaining endurance of rewriting of the one or more storage devices, and

the recompression processing includes:

reading, from the one or more storage devices, necessary compression data for compressing, in the first compression unit, data compressed in the second compression unit; and

decompressing the read necessary compression data, compressing the compression data in the first compression unit, and storing the compression data in the one or more storage devices.

6. The storage system according to claim **1**, wherein

the controller executes recompression processing of compression data stored in the one or more storage devices; and

the recompression processing includes:

determining whether each storage device of the one or more storage devices reaches a rewriting endurance within a scheduled operating time;

when determining that each storage device of the one or more storage devices does not reach a rewriting endurance within the scheduled operating time, determining, as a recompression target, data compressed in the second compression unit stored in the one or more storage devices;

reads, from the one or more storage devices, necessary compression data for compressing the recompression target in the first compression unit, and

decompressing the necessary compression data having been read, compressing the compression data in the first compression unit, and storing the compression data in the one or more storage devices.

7. A data compression method in a storage system, the data compression method wherein

the storage system

can compress data in different compression units, and

collectively compresses data of one or a plurality of consecutive addresses in each compression unit of the different compression units, and

in the data compression method, the storage system receives write data,

determines whether read of data stored in the one or more storage devices is necessary for compression of the write data by a first compression unit,

determines compression of the write data in the first compression unit in a case where the read is not necessary, and

determines compression by the first compression unit or compression by a second compression unit smaller than the first compression unit based on a remaining endurance of rewriting of the one or more storage devices in a case where the read is necessary.

8. The data compression method according to claim **7**, wherein

an address range in each compression unit of the different compression units is fixed.

9. The data compression method according to claim **7**, wherein

the storage system determines compression in a second compression unit smaller than the first compression unit when determining that any storage device of the one or more storage devices reaches a rewriting endurance within a preset scheduled operating time.

10. The data compression method according to claim **7**, wherein

the second compression unit matches a write unit of the write data to the storage system.

11. The data compression method according to claim **7**, wherein

the storage system determines a presence or absence of execution of recompression processing of data compressed in the second compression unit stored in the one or more storage devices based on a remaining endurance of rewriting of the one or more storage devices, and

the recompression processing includes:

reading, from the one or more storage devices, necessary compression data for compressing, in the first compression unit, data compressed in the second compression unit; and

decompressing the read necessary compression data, compressing the compression data in the first compression unit, and storing the compression data in the one or more storage devices.

12. The data compression method according to claim **7**, wherein

recompression processing of compression data stored in the one or more storage devices is executed; and

the recompression processing includes:

determining whether each storage device of the one or more storage devices reaches a rewriting endurance within a scheduled operating time;

when determining that each storage device of the one or more storage devices does not reach a rewriting endurance within the scheduled operating time, determining, as a recompression target, data compressed in the second compression unit stored in the one or more storage devices;

reads, from the one or more storage devices, necessary compression data for compressing the recompression target in the first compression unit, and

decompressing the necessary compression data having been read, compressing the compression data in the first compression unit, and storing the compression data in the one or more storage devices.

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