

Transferring Storage Devices Within Storage Device Testing Systems

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This U.S. patent application is a continuation-in-part of, and claims
priority under 35 U.S.C. §120 from, U.S. Patent Application 12/104,536, filed on
5 April 17, 2008. The disclosures of this prior application is considered part of the
disclosure of this application and is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] This disclosure relates to transferring storage devices within storage
device testing systems.

BACKGROUND

[0003] Disk drive manufacturers typically test manufactured disk drives for
compliance with a collection of requirements. Test equipment and techniques exist
for testing large numbers of disk drives serially or in parallel. Manufacturers tend to
test large numbers of disk drives simultaneously in batches. Disk drive testing
15 systems typically include one or more racks having multiple test slots that receive
disk drives for testing.

[0004] The testing environment immediately around the disk drive is closely
regulated. Minimum temperature fluctuations in the testing environment are critical
for accurate test conditions and for safety of the disk drives. The latest generations of
20 disk drives, which have higher capacities, faster rotational speeds and smaller head
clearance, are more sensitive to vibration. Excess vibration can affect the reliability
of test results and the integrity of electrical connections. Under test conditions, the
drives themselves can propagate vibrations through supporting structures or fixtures
to adjacent units. This vibration "cross-talking," together with external sources of
25 vibration, contributes to bump errors, head slap and non-repetitive run-out (NRRO),
which may result in lower test yields and increased manufacturing costs.

[0005] Current disk drive testing systems use an operator, a robotic arm, or a
conveyer belt to individually feed disk drives to a transfer location for loading into the
testing system for testing. A robotic arm of the testing system individually retrieves
30 the disk drives from the transfer location and loads them in test slots for testing.

SUMMARY

[0006] One aspect of the disclosure provides a method of transferring storage devices within a storage device testing system that includes actuating an automated transporter (e.g. robotic arm, gantry system, or multi-axis linear actuator) to substantially simultaneously retrieve multiple storage devices presented for testing, and actuating the automated transporter to substantially simultaneously deliver the retrieved storage devices to respective test slots of the storage device testing system and to substantially simultaneously insert each storage device in their respective test slot.

[0007] Another aspect of the disclosure provides a method of transferring storage devices within a storage device testing that includes actuating an automated transporter to substantially simultaneously retrieve storage devices from respective test slots of the storage device testing system and actuating the automated transporter to deliver the retrieved storage devices to a station and substantially simultaneously release each storage device at the station.

[0008] Implementations the disclosure may include one or more of the following features. In some implementations, the method includes actuating the automated transporter to substantially simultaneously retrieve multiple storage device transporters and actuating the automated transporter to substantially simultaneously retrieve the storage devices using the storage device transporters to carry the storage devices. In some examples, actuating the automated transporter to substantially simultaneously retrieve multiple storage device transporters, actuating the automated transporter to substantially simultaneously retrieve the storage devices presented for testing by carrying each of the storage devices with respective storage device transporters, and actuating the automated transporter to substantially simultaneously deliver the storage device transporters, each carrying one of the storage devices, to the respective test slots. In some examples, the method also includes inserting each storage device transporter substantially simultaneously into its respective test slot, engaging the carried storage device with a respective connector of the storage device testing system. The inserted storage device transporters provides closure of their respective test slots.

[0009] In some implementations, the automated transporter uses transporter couplers to engage and couple to the storage device transporters. The transporter

couplers arranged in at least a one-dimensional array. The method may include carrying the retrieved storage devices substantially parallel to one another. In such cases, the transporter couplers may be arranged substantially parallel to one another and spaced horizontally and/or vertically from each other (e.g., in a one or multi-
5 dimensional array). In other examples, the couplers are arranged at non-parallel angles with one another.

[0010] In some implementations, the storage devices are present in a storage device tote presented to the storage device testing system. The automated transporter retrieves multiple storage devices substantially simultaneously from the storage
10 device tote with corresponding storage device transporters by positioning the storage device transporters below their respective storage devices, lifting the storage devices each off a storage device support of the storage device tote, and carrying the storage devices in the storage device transporters away from the storage device tote.

[0011] The automated transporter may include a manipulator configured to
15 transport multiple storage devices. For example, in the case of a robotic arm as the automated transporter, the manipulator is secured to a distal end of the robot arm. The manipulator includes a manipulator body and multiple couplers disposed on the manipulator body and arranged substantially parallel to one another and/or in at least a one-dimensional array. Each coupler is configured to releasably attach to a storage
20 device transporter. In some examples, the manipulator includes first and second connectors or couplers disposed on a manipulator body and arranged in a substantially V-shaped configuration with respect to each other. The couplers are configured to releasably attach to a storage device transporter.

[0012] Another aspect of the disclosure provides a method of transferring
25 storage devices within a storage device testing system includes actuating an automated transporter having a manipulator to retrieve an untested storage device presented for testing. The manipulator is configured to transport multiple storage devices. The method includes actuating the automated transporter to deliver the retrieved untested storage device to a respective test slot of the storage device testing
30 system and insert the untested storage device in its respective test slot for testing.

[0013] Implementations of this aspect of the disclosure may include one or more of the following features. In some implementations, the manipulator includes first and second couplers disposed on a manipulator body and arranged in a

substantially V-shaped configuration with respect to each other. In other implementations, the couplers are arranged substantially parallel to each other and spaced from one another along one or two directional axis. In additional examples, the first and second couplers are disposed 180 degrees from one another. The couplers are configured to releasably attach to a storage device transporter.

[0014] In some examples, the method includes actuating the automated transporter to retrieve a storage device transporter, actuating the automated transporter to retrieve the untested storage device presented for testing by carrying the untested storage device with the storage device transporter, and actuating the automated transporter to deliver the storage device transporter to the respective test slot. The storage device transporter is inserted into the test slots, engaging the carried untested storage device with a respective coupler of the storage device testing system. The inserted storage device transporter provides closure of its respective test slot.

[0015] In some implementations, the untested storage device is present in a storage device tote presented to the storage device testing system. The automated transporter retrieves the untested storage device from the storage device tote with the corresponding storage device transporter by positioning the storage device transporter below the untested storage device, lifting the untested storage device off a storage device support of the storage device tote, and carrying the untested storage device in the storage device transporter away from the storage device tote.

[0016] In some implementations, the method includes actuating the automated transporter and the manipulator to retrieve a tested storage device from its respective test slot and carrying the tested storage device to a destination location, such as a destination storage device tote. The method may include actuating the automated transporter to retrieve the tested storage device from its respective test slot by actuating the manipulator to engage a respective storage device transporter of the tested storage device and carrying the tested storage device with its respective storage device transporter to the destination location. The method may include actuating the automated transporter to deliver the storage device carried by its respective storage device transporter to a receptacle of a destination storage device tote.

[0017] In yet another aspect of the disclosure, a method of transferring storage devices within a storage device testing system includes actuating an automated transporter having a manipulator to retrieve a first storage device housed in a first test

slot of the storage device testing system. The manipulator is configured to transport multiple storage devices. The method includes actuating the automated transporter to deliver the retrieved first storage device to a second test slot, actuating the automated transporter to retrieve a second storage device from the second test slot while carrying
5 the first storage device, and actuating the automated transporter to insert the first storage device into the second test slot while carrying the second storage device.

[0018] Implementations of this aspect of the disclosure may include one or more of the following features. In some implementations, the method includes actuating the automated transporter to deliver the retrieved second storage device to
10 the first test slot, and

actuating the automated transporter to insert the second storage device into the first test slot. The manipulator includes a manipulator body and first and second couplers disposed on the manipulator body. The couplers are arranged substantially parallel to one another or in a substantially V-shaped configuration with respect to each other
15 and are each configured to releasably attach to a storage device transporter. The manipulator transports the first and second storage devices in corresponding releasably attached storage device transporters. In examples where the storage devices are each carried in a corresponding storage device transporter, inserting each storage device into one of the test slots includes inserting the corresponding storage
20 device transporter into the respective test slot, engaging the carried storage device with a respective coupler of the storage device testing system, the inserted storage device transporter providing closure of its respective test slot.

[0019] Another aspect of the disclosure provides a storage device testing system that includes an automated transporter, at least one rack about the automated
25 transporter for access by the automated transporter, and multiple test slots housed by each rack. Each test slot is configured to receive a storage device for testing. A transfer station, arranged for access by the automated transporter, presents multiple storage devices for testing. A manipulator attached to the automated transporter includes multiple couplers arranged in at least a one-dimensional array and may be
30 substantially parallel to one another. Each coupler is configured to transport a storage device.

[0020] Implementations of this aspect of the disclosure may include one or more of the following features. The manipulator is configured to releasably attach to

multiple storage device transporters. In some implementations, the manipulator includes a manipulator body and multiple couplers disposed on the manipulator body. The couplers are spaced from one another in an arrangement that corresponds to a test slot layout, allowing the manipulator to substantially simultaneously service multiple test slots.

[0021] In some examples, the transfer station includes a transfer station housing configured to receive and support multiple storage device totes in a presentation position for servicing by the automated transporter. Each storage device tote includes a tote body defining multiple storage device receptacles configured to each house a storage device. The manipulator may include a manipulator body and multiple couplers disposed on the manipulator body. The couplers are spaced from one another in an arrangement that corresponds to a tote receptacle layout, allowing the manipulator to substantially simultaneously service multiple tote storage device receptacles. Each coupler may be arranged substantially parallel to one another for holding storage devices substantially parallel to one another. In some examples, the transfer station includes a conveyor for continuous transporting of storage devices to and from the storage device testing system.

[0022] Another aspect of the disclosure provides a manipulator for a storage device testing system that includes a manipulator body and multiple couplers disposed on the manipulator body. The couplers are spaced from one another in an arrangement that corresponds to a storage device servicing layout, allowing the manipulator to substantially simultaneously service multiple storage device at once.

[0023] In some implementations, the storage device servicing layout is a test slot layout of the storage device testing system, allowing the manipulator to substantially simultaneously service multiple test slots. The storage device servicing layout may also be a tote receptacle layout, allowing the manipulator to substantially simultaneously service multiple tote storage device receptacles of a tote that carries storage devices. In some implementations, the storage device servicing layout entails arranging the couplers substantially parallel to one another and/or in at least a one-dimensional array according to a coupler spacing, allowing the manipulator to transport storage devices substantially parallel to one another and/or in an array configuration. The storage device servicing layout may entail arranging the couplers

in at least a two-dimensional array according to first and second coupler spacings (e.g., horizontal and vertical spacings).

[0024] The details of one or more implementations of the disclosure are set forth in the accompanying drawings and the description below. Other features, objects, and advantages will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

[0025] FIG. 1 is a perspective view of a storage device testing system and a transfer station.

10 [0026] FIG. 2 is a top view of a storage device testing system and a transfer station.

[0027] FIG. 3 is a perspective view of a storage device testing system and a transfer station.

15 [0028] FIG. 4 is a perspective view of a storage device being inserted into a test slot of a storage device testing system.

[0029] FIG. 5 is a perspective view of a storage device transporter.

[0030] FIG. 6 is a perspective view of a storage device transporter carrying a storage device.

20 [0031] FIG. 7 is a bottom perspective view of a storage device transporter carrying a storage device.

[0032] FIG. 8 is a perspective view of a robotic arm with a manipulator secured to its distal end.

[0033] FIG. 9 is an elevated front perspective view of a manipulator for a robotic arm.

25 [0034] FIG. 10 is a elevated rear perspective view of the manipulator shown in FIG. 9.

[0035] FIG. 11 is an elevated front perspective view of a manipulator for a robotic arm.

30 [0036] FIG. 12 is a perspective view of a manipulator having two manipulator couplers arranged substantially horizontally spaced apart.

[0037] FIG. 13 is a perspective view of a manipulator having two manipulator couplers arranged substantially vertically spaced apart.

[0038] FIG. 14 is a perspective view of a manipulator having multiple manipulator couplers each spaced apart from one another.

[0039] FIG. 15 is a perspective view of a storage device tote in a loading position.

5 [0040] FIG. 16 is a perspective view of a storage device tote in a presentation position.

[0041] FIG. 17 is a perspective view of a transfer station.

[0042] FIG. 18 is a perspective view of a tote in a presentation position for placement on a tote presentation support system of a transfer station.

10 [0043] FIG. 19 is a perspective view of a storage device testing system with a conveyor for moving storage devices and/or transporters carrying storage devices.

[0044] Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0045] Bulk feeding of storage devices in a storage device testing system is
15 advantageous over manual individual feeding of storage devices by providing increased through-put and efficiency of the storage device testing system, inter alia. As will be discussed in detail, presenting multiple storage device totes (also referred to as totes), which hold multiple storage devices, to a storage device testing system allows continual storage device testing, disk sorting amongst multiple storage device
20 totes, minimal user intervention, and increased efficiency over current systems, inter alia. Bulk feeding of storage devices in storage device totes provides the advantage of shop floor flexibility (e.g. by providing the ability to easily redirect a storage device tote or a cart or trolley carrying storage device totes versus rerouting fixed conveyors). An operator can present a batch of drives (e.g. via the storage device
25 tote) to the storage device testing system and then walk away to service another system. Bulk feeding of storage devices in storage device totes also allows automatic sorting of tested drives with the storage device totes, as will be discussed below.

[0046] A storage device, as used herein, includes disk drives, solid state drives, memory devices, and any device that requires asynchronous testing for
30 validation. A disk drive is generally a non-volatile storage device which stores digitally encoded data on rapidly rotating platters with magnetic surfaces. A solid-state drive (SSD) is a data storage device that uses solid-state memory to store persistent data. An SSD using SRAM or DRAM (instead of flash memory) is often

called a RAM-drive. The term solid-state generally distinguishes solid-state electronics from electromechanical devices.

[0047] Referring to FIGS. 1-3, in some implementations, a storage device testing system 100 includes at least one automated transporter 200 (e.g. robotic arm, gantry system, or multi-axis linear actuator) defining a first axis 205 (see FIG. 3) substantially normal to a floor surface 10. In the examples shown, the automated transporter 200 comprises a robotic arm 200 operable to rotate through a predetermined arc about the first axis 205 and to extend radially from the first axis 205. The robotic arm 200 is operable to rotate 360° about the first axis 205 and includes a manipulator 700 disposed at a distal end of the robotic arm 200 to handle one or more storage devices 500 and/or storage device transporters 550 to carry the storage devices 500 (see e.g. FIGS. 5-6). Multiple racks 300 are arranged around the robotic arm 200 for servicing by the robotic arm 200. Each rack 300 houses multiple test slots 310 configured to receive storage devices 500 for testing. The robotic arm 200 defines a substantially cylindrical working envelope volume 210, with the racks 300 being arranged within the working envelope 210 for accessibility of each test slot 310 for servicing by the robotic arm 200. The substantially cylindrical working envelope volume 210 provides a compact footprint and is generally only limited in capacity by height constraints. In some examples, the robotic arm 200 is elevated by and supported on a pedestal or lift 250 on the floor surface 10. The pedestal or lift 250 increases the size of the working envelope volume 210 by allowing the robotic arm 200 to reach not only upwardly, but also downwardly to service test slots 310. The size of the working envelope volume 210 can be further increased by adding a vertical actuator to the pedestal or lift 250.

[0048] The automated transporter 200 (e.g. robotic arm) is configured to independently service each test slot 310 to provide a continuous flow of storage devices 500 through the testing system 100. A continuous flow of individual storage devices 500 through the testing system 100 allows random start and stop times for each storage device 500, whereas other systems that require batches of storage devices 500 to be run all at once as an entire testing loaded must all have the same start and end times. Therefore, with continuous flow, storage devices 500 of different capacities can be run at the same time and serviced (loaded/unloaded) as needed.

[0049] Referring to FIGS. 3-4, the storage device testing system 100 includes a transfer station 400 configured for bulk feeding of storage devices 500 to the automated transporter 200 (e.g. a robotic arm, as shown). The automated transporter 200 independently services each test slot 310 by transferring a storage device 500 between the transfer station 400 and the test slot 310. The transfer station 400 houses one or more totes 600 carrying multiple storage devices 500 presented for servicing by the automated transporter 200. The transfer station 400 is a service point for delivering and retrieving storage devices 500 to and from the storage device testing system 100. The totes 600 allow an operator to deliver and retrieve a collection of storage devices 500 to and from the transfer station 400. In the example shown in FIG. 3, each tote 600 is accessible from respective tote presentation support systems 420 in a presentation position and may be designated as a source tote 600 for supplying a collection of storage devices 500 for testing or as a destination tote 600 for receiving tested storage devices 500 (or both). Destination totes 600 may be classified as "passed return totes" or "failed return totes" for receiving respective storage devices 500 that have either passed or failed a functionality test, respectively.

[0050] In implementations that employ storage device transporters 550 for manipulating storage devices 500, as shown in FIG. 4, the robotic arm 200 is configured to remove a storage device transporter 550 from one of the test slots 310 with the manipulator 700, then pick up a storage device 500 from one the totes 600 presented at the transfer station 400 with the storage device transporter 550, and then return the storage device transporter 550, with a storage device 500 therein, to the test slot 310 for testing of the storage device 500. After testing, the robotic arm 200 retrieves the tested storage device 500 from the test slot 310, by removing the storage device transporter 550 carrying the tested storage device 500 from the test slot 310 (i.e., with the manipulator 700), carrying the tested storage device 500 in the storage device transporter 550 to the transfer station 400, and manipulating the storage device transporter 550 to return the tested storage device 500 to one of the totes 600 at the transfer station 400.

[0051] The test slot 310, shown in FIG. 4, defines an opening 312 configured to receive the storage device transporter 550, which in this case provides closure of the test slot 310. The storage device transporter 550 is configured to receive the storage device 500, as shown in FIG. 5, and be handled by the automated transporter

200. In use, one of the storage device transporters 550 is removed from one of the test slots 310 with the robot 200 (e.g., by grabbing, or otherwise engaging, the indentation 552 of the transporter 550 with the manipulator 700 of the robot 200). In some examples, as illustrated in FIGS. 5-7, the storage device transporter 550 includes a frame 560 defining a substantially U-shaped opening 561 formed by sidewalls 562, 564 and a base plate 566 that collectively allow the frame 560 to fit around a storage device support (not shown) in the tote 600 so that the storage device transporter 550 can be moved (e.g., via the robotic arm 200) into a position beneath one of the storage devices 500 housed in one of multiple storage device receptacles 620 defined by the tote 600 (see e.g., FIGS. 8-9). The storage device transporter 550 can then be raised (e.g., by the robotic arm 310) into a position engaging the storage device 600 for removal from the tote 600.

[0052] With the storage device 500 in place within the frame 560 of the storage device transporter 550, the storage device transporter 550 and the storage device 500 together can be moved by the robotic arm 200 for placement within one of the test slots 310, as shown in FIG. 4. In some implementations, the manipulator 700 is also configured to initiate actuation of a clamping mechanism 570 disposed in the storage device transporter 550. This allows actuation of the clamping mechanism 570 before the transporter 550 is moved from the tote 600 to the test slot 310 to inhibit movement of the storage device 500 relative to the storage device transporter 550 during the move. Prior to insertion in the test slot 310, the manipulator 700 can again actuate the clamping mechanism 570 to release the storage device 500 within the frame 560. This allows for insertion of the storage device transporter 550 into one of the test slots 310, until the storage device 500 is in a test position with a storage device connector 510 engaged with a test slot connector (not shown). The clamping mechanism 570 may also be configured to engage the test slot 310, once received therein, to inhibit movement of the storage device transporter 550 relative to the test slot 310. In such implementations, once the storage device 500 is in the test position, the clamping mechanism 570 is engaged again (e.g., by the manipulator 700) to inhibit movement of the storage device transporter 550 relative to the test slot 310. The clamping of the transporter 550 in this manner can help to reduce vibrations during testing. In some examples, after insertion, the storage device transporter 550

and storage device 500 carried therein are both clamped or secured in combination or individually within the test slot 310.

[0053] Referring to FIGS. 8-11, the manipulator 700 is secured to a distal end 202 of the robotic arm 200. In some implementations, the manipulator 700 includes first and second arms 720, 730 disposed on a manipulator body 710. In the examples shown in FIGS. 9-11, the first and second arms 720, 730 are arranged in a substantially V-shaped configuration with respect to each other. In some implementations, the arms 720, 730 can be disposed in other arrangements, such as 180 degrees from each other or some other angle therebetween. The arms 720, 730 each have couplers 740 configured to releasably attach to a storage device transporter 550. In the examples shown, each coupler 740 includes first and second tabs 742, 744 oppositely coupled to a tab actuator 750 disposed on the arm 720, 730. The tab actuator 750 is operable to move its coupled tabs 742, 744 in opposing directions to releasably engage and hold a storage device transporter 550. To grab the storage device transporter 550, the robotic arm 200 and manipulator 700 are actuated to maneuver one of the couplers 740 to place the tabs 742, 744 into the indentation 552 of the storage device transporter 550 and then actuate the tab actuator 740 to move the tabs 742, 744 away from each other and engage the indentation 552 to releasably attach to the storage device transporter 550. In some examples, the tabs 742, 744 are hook shaped and/or have friction pads to engage the indentation 552 of the storage device transporter 550. Each arm 720, 730 of the manipulator 700 has first and second clamp actuators 762, 764 configured to engage the clamping mechanism 570 of the storage device transporter 550. The clamp actuators 762, 764 may be operable to push or pull on the clamping mechanism 570 to engage/disengage the clamping mechanism 570.

[0054] Referring to FIGS. 12-14, in some examples, the manipulator 700 includes multiple manipulator couplers 725 disposed on a manipulator body 710 and arranged in substantially the same orientation with respect to each other (e.g., parallel), with each manipulator coupler 725 spaced from one another (e.g., vertically and/or horizontally). FIG. 12 illustrates an example of the manipulator 700 having first and second manipulator couplers 725A, 725B arranged with a horizontal spacing H. FIG. 13 illustrates an example of the manipulator 700 having first and second manipulator couplers 725A, 725B arranged with a vertical spacing V. FIG. 14

illustrates an example of the manipulator 700 having first, second, third, and fourth manipulator couplers 725A, 725B, 725C, 725D arranged with the horizontal spacing H between the first and second couplers 725A, 725B as well as the third and fourth couplers 725C, 725D, and the vertical spacing V between the first and second
5 couplers 725A, 725B and the third and fourth couplers 725C, 725D. In some examples, a third axis of spacing is used to offset various manipulator couplers 725 from others in three directions.

[0055] Each manipulator coupler 725 is configured to engage and releasably hold a storage device transporter 550. The manipulator couplers 725 may be arranged
10 to allow the manipulator 700 to deliver and retrieve disc drives 500 from multiple test slots 310 substantially simultaneously. The manipulator couplers 725 are arranged to accommodate the spacing (e.g., single or multi-directional) between one or more groups of test slots 310 (e.g., adjacent and/or non-adjacent test slots 310), such that the robotic arm 200 can maneuver the manipulator 700 to interact with multiple test
15 slots 310 at once. For example, to interact with test slots 310 arranged in columns and rows in the racks 300, the manipulator couplers 725 are arranged with the appropriate spacing(s) H,V such that the manipulator couplers 725 substantially align with respective test slots 310 for delivering or retrieving disc drives 500 and/or transporters 550 to or from the test slots 310. The tote 600 may be configured to accommodate
20 and hold disc drives 500 in an arrangement that spaces the disc drives 500 in same manner as the test slots 310 are arranged in the racks 300. Therefore, the manipulator 700 may interact with totes 600 having storage device receptacles 620 (FIG. 15) and with racks 300 having test slots 310 in same manner, e.g., as when both the storage device receptacles 620 and the test slots 310 are arranged in substantially similar rows
25 and columns. The manipulator couplers 725 may be arranged such that the spacings H, V are multiples of the spacing between adjacent storage device receptacles 620 and/or test slots 310. For example, the manipulator couplers 725 may be arranged so as to retrieve storage devices 500 from non-adjacent storage device receptacles 620 (e.g., first and fourth positions), while delivering the retrieved storage devices 500 to
30 adjacent test slots 310. The converse may be suitable as well.

[0056] The manipulator 700 may retrieve or deliver the storage devices 500 or storage device transporters 550 carrying storage devices 500 sequentially, randomly, or substantially simultaneously. The manipulator couplers 725 may retrieve or deliver

the storage devices 500 or storage device transporters 550 carrying storage devices 500 into horizontally or vertically adjacent, or horizontally or vertically non-adjacent storage device receptacles 620. Further, the manipulator couplers 725 may retrieve or deliver the storage devices 500 or storage device transporters 550 carrying storage devices 500 into horizontally or vertically adjacent, or horizontally or vertically non-adjacent test slots.

[0057] For example, in implementations where the manipulator couplers 725 are spaced horizontally (FIG. 12) with substantially no vertical spacing V (e.g., in a row), the manipulator 700 may deliver and retrieve storage devices 500 to and from storage device receptacles 620 in the same row of the tote 600 as well as deliver and retrieve storage device transporters 550 carrying storage devices 500 to and from test slots 310 in the same row of a rack 300. In another example, in implementations where the manipulator couplers 725 are spaced vertically (FIG. 13) with substantially no horizontal spacing H (e.g., in a row), the manipulator 700 may deliver and retrieve storage devices 500 to and from storage device receptacles 620 in the same column of the tote 600 as well as deliver and retrieve storage device transporters 550 carrying storage devices 500 to and from test slots 310 in the same column of a rack 300. Combinations of these examples are possible as well, such as diagonally spaced manipulator couplers 725. In examples, such as shown in FIG. 14, where the manipulator 700 includes a two dimensional array of manipulator couplers 725, the manipulator 700 can deliver and retrieve storage devices 500 to and from storage device receptacles 620 in the multiple rows and columns of the tote 600 as well as deliver and retrieve storage device transporters 550 carrying storage devices 500 to and from multiple rows and columns test slots 310 of a rack 300

[0058] In the example illustrated in FIGS. 15-16, the tote 600 includes a tote body 610 having a front side 611, a back side 612, a top side 613, a bottom side 614, a right side 615 and a left side 616. The tote body 610 defines multiple storage device receptacles 620 in the front side 611 that are each configured to house a storage device 500. In some examples, the tote 600 rests on its back side 612 while in the loading position, such that the storage device receptacles 620 are substantially vertical and face upward, as shown in FIG. 12. In other examples, the tote 600 is held in another orientation while in the loading position, such as at an incline or in a vertical orientation, as with the presentation position. In the presentation position, the tote

600 rests on its bottom side 614, such that the storage device receptacles 620 are substantially horizontal and face laterally, as shown in FIG. 13. The tote body 610 defines arm grooves 630 in the right and left sides 615, 616 of the tote body 610 that are configured to support the tote 600.

5 [0059] In the example shown, each storage device receptacle 620 includes a storage device support 622 configured to support a central portion 502 (see FIG. 7) of the received storage device 500 to allow manipulation of the storage device 500 along non-central portions. In some implementations, the storage device support 622 is configured to support the storage device 500 at an incline, while the tote 600 is in a
10 substantially vertical orientation, such that the storage device 500 has a tendency to slide deeper into the storage device receptacle 620, rather than out of the storage device receptacle 620. To remove a housed storage device 500 from the storage device receptacle 620, the storage device transporter 550 is positioned below the storage device 500 (e.g. by the robotic arm 200) in the storage device receptacle 620
15 and elevated to lift the storage device 500 off of the storage device support 622. The storage device transporter 550 is then removed from the storage device receptacle 620 while carrying the storage device 500 for delivery to a destination target, such as a test slot 310. In some examples, the storage device receptacle 620 of the tote 600 and the manipulator couplers 725 can be spaced to have substantially the same vertical and/or
20 horizontal spacing of the test slots 310. The manipulator 700 retrieves or delivers multiple storage devices 500 or storage device transporters 550 carrying storage devices 500 substantially simultaneously with multiple manipulator couplers 725 from the storage device receptacles 620 of the tote 600, transports the storage devices 500 or storage device transporters 550 carrying storage devices 500 to one or more
25 racks 300 and substantially simultaneously delivers them to multiple test slots 310. The same procedure may be used in reverse to move storage devices 500 or storage device transporters 550 carrying storage devices 500 from the test slots 310 back to one or more totes 600. In some examples, the manipulator couplers 725 are configured to move in one or more directions (e.g., via single or multi-axis drive or
30 stage) to accommodate different spacings between storage device receptacle 620 and/or test slots 310.

[0060] Referring to FIG. 17, in some implementations, the transfer station 400 includes a transfer station housing 410 and multiple tote presentation support systems

420 disposed on the transfer station housing 410. Each tote presentation support system 420 is configured to receive and support a storage device tote 600 in a presentation position for servicing by the storage device testing system 100.

[0061] In some implementations, the tote presentation support systems 420 are each disposed on the same side of the transfer station housing 410 and arranged vertically with respect to each other. Each tote presentation support systems 420 has a different elevation with respect to the others. In some examples, as shown in FIG. 18, the tote presentation support system 420 includes first and second opposing pairs 422, 424 of tote support arms 426 configured to be received by respective arm grooves 630 defined by the tote body 610 of the storage device tote 600.

[0062] Referring again to FIG. 17, a tote mover 430 is disposed on the transfer station housing 410 and is configured to move a pivotally coupled tote loading support 440, which is configured to receive and support a storage device tote 600. The tote loading support 440 pivots and moves between a first position and a second position. The tote mover 430 is configured to move the tote loading support 440 between the first position, for holding a storage device tote 600 in a loading position (e.g. in a horizontal orientation at the loading support's first position), and the second position, for holding a storage device tote 600 in the presentation position (e.g. in a substantially vertical orientation) at one of the tote presentation support systems 420 for servicing by the storage device testing system 100 (e.g. by the robotic arm 200). In some examples, the tote presentation support system 420 holds the tote 600 at a slightly inclined (e.g. off vertical) orientation to keep storage devices 500 from accidentally slipping out of the tote 600.

[0063] A method of performing storage device testing includes presenting multiple storage devices 500 to a storage device testing system 100 for testing and actuating an automated transporter 200 (e.g. robotic arm) to retrieve one or more storage devices 500 from the storage device tote 600 and deliver the retrieved storage device(s) 500 to corresponding test slots 310 of a rack 300 of the storage device testing system 100. The method includes actuating the automated transporter 200 to insert each storage device 500 in the test slot 310, and performing a functionality test on the storage devices 500 received by the test slot 310. The method may also include actuating the automated transporter 200 to retrieve the tested storage devices 500 from the test slot 310 and deliver the tested storage device 500 back to a

destination location. In some implementations, the method includes retrieving multiple presented storage devices 500 and delivering each of the storage devices to a respective test slot 310. In other implementations, the method includes shuffling storage devices 500 amongst test slots 310 by actuating the automated transporter 200 to remove a first storage device 500 from a first test slot 310 and carrying it with a first manipulator couplers 720, moving to a second test slot 310 and removing a second storage device 500 and carrying it with a second manipulator couplers 730, and then inserting the first storage device 500 into the second slot 310. The method may also include actuating the automated transporter 200 to move the second storage device to the first test slot 310 and inserting the second storage device 500 in the first test slot 310. For this mode of operation (storage device shuffling), the dual-armed manipulator 700 provides distinct advantages over a single-armed manipulator by allowing direct exchanges of storage devices 500 at each stop, rather than having to take a storage device 500 out of a first test slot 310, park the storage device 500 in an empty slot 310 or in a tote 600, retrieve another storage device 500 from a second slot 310 and insert that storage device 500 into the first test slot 310, and then retrieve the parked storage device 500 and insert it in the second slot 310. The dual-armed manipulator 700 removes the step of parking one of the storage devices 500 while swapping storage devices 500 amongst two test slots 310.

destination location.

[0064] In some implementations, the method includes retrieving multiple presented storage devices 500 substantially simultaneously and delivering each of the storage devices to a respective test slot 310 substantially simultaneously. The method may includes shuffling storage devices 500 amongst test slots 310 by actuating the automated transporter 200 to remove a set of storage devices 500 from a first set of test slots 310, via multiple manipulator couplers 725, carrying them to a second set of test slots 310 and deliver them substantially simultaneously to the second set of test slots 310. Alternatively, the automated transporter 200 can deliver the set of storage devices 500 to a set of storage device receptacles 620 of a tote 600. Similarly, the method may include retrieving a set of storage devices 500 from a set of storage device receptacles 620 of a tote 600 substantially at once and deliver the set (all of them substantially at once) to multiple test slots 310.

[0065] Presenting multiple storage devices 500 for testing may be achieved by loading multiple storage devices 500 into/onto a transfer station 400, as by loading the storage devices 500 into storage device receptacles 620 defined by a storage device tote 600, and loading the storage device tote 600 into/onto the transfer station 400. A
5 tote mover 430 of the transfer station 400 is actuated to move the storage device tote 600 from a loading position to a presentation position for servicing by the storage device testing system 100. The storage device tote 600 is supported in the presentation position by one of multiple tote presentation support systems 420
disposed on the transfer station housing 410 and arranged vertically with respect to
10 each other. Multiple storage device totes 600, each housing storage devices 500, can be sequentially placed in the loading position on the transfer station 400 and moved by the tote mover 430 to its respective presentation position at one of the multiple tote presentation support systems 420 for servicing by the storage device testing system 100.

[0066] In retrieving one or more of the presented storage devices 500 for testing, the method preferably includes actuating the automated transporter 200 to retrieve one or more storage device transporter 550 (e.g. from a test slot 310 housed in a rack 300), and actuating the automated transporter 200 to retrieve one or more storage devices 500 from the transfer station 400 and carry the storage devices 500 in
20 respective storage device transporters 550. The method includes actuating the automated transporter 200 to deliver the storage device transporters 550 carrying the storage devices 500 to respective test slots 310 for performing a functionality test on the storage device 500 housed by the received storage device transporter 550 and the test slot 310. In some examples, delivering the storage device transporters 550 to the
25 test slots 310 includes inserting the storage device transporters 550 carrying the storage devices 500 into the test slots 310 in the rack 300, establishing an electric connection between the storage devices 500 and the rack 300. After testing is completed on the storage devices 500, the method includes actuating the automated transporter 200 to retrieve the storage device transporters 550 carrying the tested
30 storage device 500 from the test slots 310 and delivering the tested storage devices 500 back to a destination location, such as a destination storage device tote 600 on the transfer station 400. In some implementations, the rack 300 and two or more associated test slots 310 are configured to move storage devices 500 internally from

one test slot 310 to another test slot 310, as in the case where the test slots 310 are provisioned for different kinds of tests.

[0067] In some examples, the method includes actuating the automated transporter 200 to deposit the storage device transporter 550 in the test slot 310 after depositing the tested storage device 500 at a destination location (e.g. in a storage device receptacle 620 of a destination storage device tote 600), or repeating the method by retrieving another storage device 500 for testing (e.g. from the storage device receptacle 620 of a source storage device tote 600).

[0068] In some implementations, the automated transporter 200 includes a manipulator 700 configured to handle multiple storage devices 500 and/or storage device transporters 550 at once. For example, the automated transporter 200 can retrieve and carry one untested storage device 500 in a storage device transporter 500 held by one arm 720, 730 or manipulator coupler 725 of the manipulator 700, and deliver the untested storage device 500 to a test slot 310. At the test slot 310, the automated transporter 200 removes a storage device transporter 550 carrying a test storage device 500 currently in the test slot 310, before inserting the storage device transporter 550 carrying the untested storage device 500 into the test slot 310 for testing. The automated transporter 200 then delivers the tested storage device 500 to a destination location, such as a receptacle 620 of a destination storage device tote 600.

In another example, the automated transporter 200 can retrieve and carry two or more untested storage devices 500, one on each arm 720, 730 or on manipulators coupler 725 of the manipulator 700, and then deliver the two untested storage devices 500 to respective test slots 310 for testing. The automated transporter 700 can then be actuated to retrieve two tested storage devices 500 from their respective slots 310 (e.g. by engaging and removing their respective storage device transporters 550 with the manipulator 700), and deliver the tested storage devices 500 to a destination location, such as two receptacles 620 of one or more destination storage device totes 600. If one tested storage device 500 passed the storage device testing and the other failed, they may be placed in different destination storage device totes 600, such a “passed” storage device tote 600 and a “failed” storage device tote 600.

[0069] The manipulator 700 allows the automated transporter 200 to move multiple storage devices 500 and/or storage device transporters 550 within the storage device testing system 100 to accomplish more tasks than previously achievable by a

manipulator capable of only handling one storage device 500 and/or storage device transporter 550 at a time. The increased flexibility allows for path planning of the automated transporter 200 to optimize its movements.

[0070] Referring to FIG. 19, in some implementations, a conveyor 1900 is
5 employed instead of a tote 600 to transport storage devices 500 before, during, or after tests. The conveyor 1900 may be a conveyer belt, an automated assembly that moves storage devices 500, or an operator, inter alia, that arranges storage devices 500 in some sort of presentation system where the manipulator 700 can retrieve multiple storage devices 500. The conveyor 1900 may also include any type of suitable
10 feeding system, automated or operator-based, that presents and/or removes storage devices 500 to/from the storage device testing system 100. The manipulator 700 may remove the storage devices 500 (via the manipulator couplers 725) from the conveyor 1900 and return the storage devices 500 to the conveyor 1900 following a portion of or the completion of the disc drive testing. In some examples, the manipulator 700
15 includes a linear array of manipulator couplers 725, similar to that shown in FIG. 12, for retrieving and placing multiple disc drives 500 and/or storage device transporters 550 carrying the storage devices 500 to and from the conveyor 1900.

[0071] A number of implementations have been described. Nevertheless, it
will be understood that various modifications may be made without departing from
20 the spirit and scope of the disclosure. Accordingly, other implementations are within the scope of the following claims.

WHAT IS CLAIMED IS:

1. A method of transferring storage devices (500) within a storage device testing system (100), the method comprising:

actuating an automated transporter (200) to substantially simultaneously
5 retrieve multiple storage devices (500) presented for testing; and
actuating the automated transporter (200) to substantially simultaneously
deliver the retrieved storage devices (500) to respective test slots (310) of the storage
device testing system (100) and to substantially simultaneously insert each storage
device (500) in their respective test slot (310).

10 2. The method of claim 1, further comprising:

actuating the automated transporter (200) to substantially simultaneously
retrieve multiple storage device transporters (550);

actuating the automated transporter (200) to substantially simultaneously
15 retrieve the storage devices (500) presented for testing by carrying each of the storage
devices (500) with respective storage device transporters (550); and

actuating the automated transporter (200) to substantially simultaneously
deliver the storage device transporters (550), each carrying one of the storage devices
(500), to the respective test slots (310).

20 3. The method of claim 2, further comprising inserting each storage device
transporter (550) substantially simultaneously into its respective test slot (310),
engaging the carried storage device (500) with a respective connector of the storage
device testing system (100), the inserted storage device transporters (550) providing
25 closure of their respective test slots (310).

4. A method of transferring storage devices (500) within a storage device testing
system (100), the method comprising:

actuating an automated transporter (200) to substantially simultaneously
30 retrieve storage devices (500) from respective test slots (310) of the storage device
testing system (100); and

actuating the automated transporter (200) to deliver the retrieved storage devices (500) to a station (400, 600) and substantially simultaneously release each storage device (500) at the station (400, 600).

5 5. The method of claim 4 further comprising:

actuating the automated transporter (200) to substantially simultaneously retrieve multiple storage device transporters (550);

actuating the automated transporter (200) to substantially simultaneously retrieve the storage devices (500) from their respective test slots (310) using storage
10 device transporters (550) to carry the storage devices (500).

6. The method of any of the preceding claims, wherein the automated transporter (200) uses transporter couplers (725, 740) to engage and couple to storage device transporters (550), the transporter couplers (725, 740) arranged in at least a one-
15 dimensional array.

7. The method of claim 6, further comprising carrying the retrieved storage devices (500) substantially parallel to one another.

20 8. The method of claim 7, wherein the transporter couplers (725, 740) are arranged substantially parallel to one another and spaced at least one of horizontally and vertically from each other.

9. The method of any of the preceding claims, wherein the automated transporter
25 (200) comprises a manipulator (700), the manipulator (700) comprising:
a manipulator body (710); and
multiple couplers (725, 740) disposed on the manipulator body (710) and arranged at least a one-dimensional array, each coupler (725, 740) being configured to releasably attach to a storage device transporter (550).

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10. The method of any of the preceding claims, further comprising presenting or releasing the storage devices (500) in a storage device tote (600) presented to the storage device testing system (100).

11. The method of claim 9, wherein the automated transporter (200) retrieves multiple storage devices (500) substantially simultaneously from the storage device tote (600) with corresponding storage device transporters (550) by positioning the storage device transporters (550) below their respective storage devices (500), lifting the storage devices (500) each off a storage device support (622) of the storage device tote (600), and carrying the storage devices (500) in the storage device transporters (550) away from the storage device tote (600).

12. A storage device testing system (100) comprising:
an automated transporter (200);
at least one rack (300) arranged about the automated transporter (200) for access by the automated transporter (200);
multiple test slots (310) housed by each rack (300), each test slot (310) being configured to receive a storage device (500) for testing;
a transfer station (400) arranged for access by the automated transporter (200), the transfer station (400) presenting multiple storage devices (500) for testing; and
a manipulator (700) attached to the automated transporter (200), the manipulator (700) comprising multiple couplers (725, 740) arranged in at least a one-dimensional array, each coupler (725, 740) being configured to transport a storage device (500).

13. The storage device testing system (100) of claim 12, wherein each coupler (725, 740) is configured to releasably attach to a storage device transporter (550).

14. The storage device testing system (100) of any of claim 12 or claim 13, wherein the transfer station (400) comprises a transfer station housing (410) configured to receive and support multiple storage device totes (600) in a presentation position for servicing by the automated transporter (200), wherein each storage device tote (600) comprises a tote body (610) defining multiple storage device receptacles (620) configured to each house a storage device (500).

15. The storage device testing system (100) of any of claims 12-14, wherein the manipulator (700) comprises:

a manipulator body (710); and

5 multiple couplers (725, 740) disposed on the manipulator body (710) and spaced from one another in an arrangement that corresponds to a test slot layout, allowing the manipulator (700) to substantially simultaneously service multiple test slots (310), and/or a tote receptacle layout, allowing the manipulator (700) to substantially simultaneously service multiple tote storage device receptacles (620).

10 16. The storage device testing system (100) of claim 15, wherein each coupler (725, 740) is arranged substantially parallel to one another for holding storage devices (500) substantially parallel to one another.

17. The storage device testing system (100) of any of claims 12-16, wherein the transfer station (400) comprises a conveyor (1900).

18. A manipulator (700) for a storage device testing system (100), the manipulator (700) comprising:

a manipulator body (710); and

20 multiple couplers (725, 740) disposed on the manipulator body (710) and spaced from one another in an arrangement that corresponds to a storage device servicing layout, allowing the manipulator (700) to substantially simultaneously service multiple storage devices (500) at once.

25 19. The manipulator (700) of claim 18, wherein the storage device servicing layout comprises a test slot layout of the storage device testing system (100), allowing the manipulator (700) to substantially simultaneously service multiple test slots (310), and/or a tote receptacle layout, allowing the manipulator (700) to substantially simultaneously service multiple tote storage device receptacles (620) of a tote (600)
30 that carries storage devices (500).

20. The manipulator (700) of claim 19, wherein the storage device servicing layout comprises arranging the couplers (725, 740) at least a one or two-dimensional array according to coupler spacings (H, V).

- 5 21. The manipulator (700) of claim 19 or claim 20, wherein the storage device servicing layout comprises arranging the couplers (725, 740) substantially parallel to one another, allowing the manipulator (700) to transport storage devices (500) substantially parallel to one another.