

Engaging Test Slots

CROSS-REFERENCE TO RELATED APPLICATION

This patent application claims the benefit of priority of United States Patent Application No. 12/872,401, filed August 31, 2010, the contents of which is hereby
5 incorporated by reference in its entirety.

TECHNICAL FIELD

This disclosure relates to engaging test slots and related devices, systems, and methods.

BACKGROUND

10 Storage device manufacturers typically test manufactured storage devices for compliance with a collection of requirements. Test equipment and techniques exist for testing large numbers of storage devices serially or in parallel. Manufacturers tend to test large numbers of storage devices simultaneously. Storage device testing systems typically include one or more tester racks having multiple test slots that receive storage
15 devices for testing. In some cases, the storage devices are placed in carriers which are used for loading and unloading the storage devices to and from the test racks.

The testing environment immediately around the storage device is regulated. Minimum temperature fluctuations in the testing environment may be critical for accurate test conditions and for safety of the storage devices. In addition, 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 vibration,
25 contributes to bump errors, head slap and non-repetitive run-out (NRRO), which may result in lower yields and increased manufacturing costs. Current disk drive testing systems employ automation and structural support systems that contribute to excess vibrations in the system and/or require large footprints.

SUMMARY

In general, this disclosure relates to engaging test slots and related devices, systems, methods, and means.

5 In one aspect, a test slot is engaged with automated machinery to inhibit movement of the test slot, thereby inhibiting transmission of vibration from the test slot to its surroundings. While the automated machinery is engaged with the test slot, the automated machinery is actuated to insert a storage device into the test slot, or remove the storage device from the test slot.

10 In another aspect, an apparatus includes at least one engaging element configured to engage a test slot to inhibit movement of the test slot, thereby inhibiting transmission of vibration from the test slot to its surroundings. The apparatus further includes an automated transporter, while the at least one engaging element is engaged with the test slot, configured to insert a storage device into the test slot; or remove the storage device
15 from the test slot.

In another aspect, automated machinery includes means for engaging a test slot to inhibit movement of the test slot, thereby inhibiting transmission of vibration from the test slot to its surroundings. The automated machinery also includes means for, while the automated machinery is engaged with the test slot, inserting a storage device into the test
20 slot, or removing the storage device from the test slot.

Embodiments may include one or more of the following features. The automated machinery engages the test slot with one or more actuators. The one or more actuators include one or more first engaging elements. The test slot includes one or more second engaging elements. Engaging the test slot includes causing the one first engaging
25 elements to temporarily connect to the one or more second engaging elements. The one or more first engaging elements may include an element selected from a group consisting of: a pin, a recess, a slot, a magnet, an adhesive, a clasp, and a hook. The one or more first engaging elements may alternatively be constructed so as to present a surface to engage the test slot by friction. The one or more second engaging elements may include
30 an element selected from a group consisting of: a pin, a recess, a slot, a magnet, an

adhesive, a clasp, and a hook. The one or more second engaging elements may alternatively be constructed so as to present a surface to be engaged by friction. The automated machinery includes a robot that includes a manipulator for carrying the storage device. The actuators are coupled to the robot and/or the manipulator. The storage device is carried by a storage device transporter. The automated machinery includes a robot and a manipulator for engaging the storage device transporter, and the actuators are coupled to the robot and/or the manipulator. The at least engaging element is configured to temporarily connect to one or more second engaging elements of the test slot. The at least one engaging element includes an element selected from a group consisting of a pin, a recess, a slot, a magnet, an adhesive, a clasp, and a hook. The at least one engaging element is adapted to engage the test slot by friction. The one or more second engaging elements include an element selected from a group consisting of a pin, a recess, a slot, a magnet, an adhesive, a clasp, and a hook. The automated transporter comprises a robot that comprises a manipulator for carrying the storage device, wherein the at least one engaging element is coupled to the robot and/or the manipulator. The storage device is carried by the automated transporter.

The details of one or more embodiments 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

FIG. 1 is a perspective view of a storage device testing system.

FIG. 2A is perspective view of a test rack.

FIG. 2B is a detailed perspective view of a carrier receptacle from the test rack of FIG. 2A.

FIGS. 3A and 3B are front and back perspective views, respectively, of a test slot carrier.

FIG. 4 is a perspective view of a test slot assembly.

FIG. 5 is a top view of a storage device testing system.

FIG. 6 is a perspective view of a storage device testing system.

FIGS. 7A and 7B are perspective views of a storage device transporter.

FIG. 8A is a perspective view of a storage device transporter supporting a storage device.

FIG. 8B is a perspective view of a storage device transporter receiving a storage device.

5 FIG. 8C is a perspective view of a storage device transporter carrying a storage device aligned for insertion into a test slot.

FIG. 9 is a schematic view of test circuitry.

FIGS. 10A and 10B are perspective views of a front portion of a test slot.

10 FIG. 11 is a perspective view of a front portion of a test slot being engaged by actuators.

FIGS. 12A and 12B are perspective views of actuators.

FIG. 13 is a perspective views of a transporter being inserted into a test slot while the test slot is engaged by actuators.

Like reference symbols in the various drawings indicate like elements.

15 DETAILED DESCRIPTION

System Overview

As shown in FIG. 1, a storage device testing system 10 includes a plurality of test racks 100 (e.g., 10 test racks shown), a transfer station 200, and a robot 300 (sometimes referred to as an “automated transporter”). As shown in FIGS. 2A and 2B, each test rack
20 100 generally includes a chassis 102. The chassis 102 can be constructed from a plurality of structural members 104 (e.g., formed sheet metal, extruded aluminum, steel tubing, and/or composite members) which are fastened together and together define a plurality of carrier receptacles 106.

Each carrier receptacle 106 can support a test slot carrier 110. As shown in FIGS.
25 3A and 3B, each test slot carrier 110 supports a plurality of test slot assemblies 120. Different ones of the test slot carriers 110 can be configured for performing different types of tests and/or for testing different types of storage devices. The test slot carriers 110 are also interchangeable with each other within among the many carrier receptacles 106 within the testing system 10 allowing for adaptation and/or customization of the
30 testing system 10, e.g., based on testing needs.

A storage device, as used herein, includes disk drives, solid state drives, memory devices, and any device that benefits from asynchronous testing. 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
5 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.

As shown in FIG. 4, each test slot assembly 120 includes a storage device transporter 400, a test slot 500, and an associated air mover assembly 700. The storage
10 device transporter 400 may be used for capturing storage devices 600 (e.g., from the transfer station 200) and for transporting the storage device 600 to one of the test slots 500 for testing. The test slot includes a rear portion 500B and a front portion 500A. The front portion 500A defines a test compartment 526 for receiving one of the storage device transporters 400. The rear portion 500B carries a connection interface board 520, which
15 carries a connection interface circuit 182 (FIG. 9).

Referring to FIGS. 5 and 6, the robot 300 includes a robotic arm 310 and a manipulator 312 (FIG. 5) disposed at a distal end of the robotic arm 310. The robotic arm 310 defines a first axis 314 (FIG. 6) normal to a floor surface 316 and is operable to rotate through a predetermined arc about and extends radially from the first axis 314
20 within a robot operating area 318. The robotic arm 310 is configured to independently service each test slot 500 by transferring storage devices 600 between the transfer station 200 and the test racks 100. In some embodiments, the robotic arm 310 is configured to remove a storage device transporter 400 from one of the test slots 500 with the manipulator 312, then pick up a storage device 600 from the transfer station 200 with the
25 storage device transporter 400, and then return the storage device transporter 400, with a storage device 600 therein, to the test slot 500 for testing of the storage device 600. After testing, the robotic arm 310 retrieves the storage device transporter 400, along with the supported storage device 600, from one of the test slots 500 and returns it to the transfer station 200 (or moves it to another one of the test slots 500) by manipulation of the
30 storage device transporter 400 (i.e., with the manipulator 312). In some embodiments, the robotic arm 310 is configured to pick up a storage device 600 from the transfer station

200 with the manipulator 312, then move the storage device 600 to a test slot 500, and deposit the storage device 600 in the test slot 500 by means of depositing the storage device 600 in the storage device transporter 400 and then inserting the storage device transporter in the test slot 500. After testing, the robotic arm 310 uses the manipulator
5 312 to remove the storage device 600 from the storage device transporter 400 and return it to the transfer station 200.

Referring to FIGS. 7A and 7B, the storage device transporter 400 includes a frame 410 and a clamping mechanism 450. The frame 410 includes a face plate 412. As shown in FIG. 7A, along a first surface 414, the face plate 412 defines an indentation
10 416. The indentation 416 can be releaseably engaged by the manipulator 312 (FIG. 5) of the robotic arm 310, which allows the robotic arm 310 to grab and move the transporter 400. In use, one of the storage device transporters 400 is removed from one of the test slots 500 with the robot 300 (e.g., by grabbing, or otherwise engaging, the indentation 416 of the transporter 400 with the manipulator 312 of the robot 300). The frame 410
15 defines a substantially U-shaped opening 415 formed by sidewalls 418 and a base plate 420.

Referring to FIGS. 8A, 8B, and 8C, with the storage device 600 in place within the frame 410 of the storage device transporter 400, the storage device transporter 400 and the storage device 600 together can be moved by the robotic arm 310 (FIG. 5) for
20 placement within one of the test slots 500. The manipulator 312 (FIG. 5) is also configured to initiate actuation of a clamping mechanism 450 disposed in the storage device transporter 400. Actuating the clamping mechanism 450 inhibits movement of the storage device 600 relative to the storage device transporter 400. Releasing the clamping mechanism 450 allows for insertion of the storage device transporter 400 into one of the
25 test slots 500. The clamping mechanism 450 may also be configured to engage the test slot 500, once received therein, to inhibit movement of the storage device transporter 400 relative to the test slot 500. In such implementations, once the storage device 600 is in the test position, the clamping mechanism 450 is engaged again (e.g., by the manipulator 312) to inhibit movement of the storage device transporter 400 relative to the test slot
30 500. The clamping of the transporter 400 in this manner can help to reduce vibrations during testing. Additional details of the transporter 400 and the clamping mechanism 450

and other details and features combinable with those described herein may be found in the following U.S. patent application filed July 15, 2009, entitled “CONDUCTIVE HEATING”, with attorney docket number: 18523-0097001, inventors: Brian S. Merrow et al., and having assigned serial number 12/503,593, the entire contents of the which are
5 hereby incorporated by reference.

Referring to FIG. 9, in some implementations, the storage device testing system 10 can also include at least one computer 130 in communication with the test slots 500. The computer 130 may be configured to provide inventory control of the storage devices 600 and/or an automation interface to control the storage device testing system 10. Test
10 electronics 160 are in communication with each test slot 500. The test electronics 160 are in electrical communication with connection interface circuits 182 that are disposed within each the test slots 500. These connection interface circuits 182 are arranged for electrical communication with a storage device 600 received within the associated test slot 500, and thereby provide for communication between the test electronics 160 and
15 storage devices 600 within the test slots 500, e.g., for executing test routines. The test routines may include a functionality test, which can include testing the amount of power received by the storage device 600, the operating temperature, the ability to read and write data, and the ability to read and write data at different temperatures (e.g. read while hot and write while cold, or vice versa). The functionality test may test every memory
20 sector of the storage device 600 or only random samplings. The functionality test may test an operating temperature of the storage device 600 and also the data integrity of communications with the storage device 600.

As shown in FIG. 9, a power system 170 supplies power to the storage device testing system 10. The power system 170 may monitor and/or regulate power to the
25 received storage device 600 in the test slot 500

Engaging the Test Slot

As mentioned above, storage devices (e.g., storage device 600) are susceptible to shock and vibration during operation and testing. Shock and vibration events can also
30 occur, for example, when a storage device is inserted or removed from a test slot 500. During testing, storage devices are frequently swapped out for different storage devices

while the surrounding storage devices are operating or being tested. In some examples, it can be difficult to insert or remove a storage device from the test slot 500 without causing a frame (e.g., frame 502) of the test slot 500 from bumping into the chassis 102 of the test rack 100 (FIGS. 2A and 2B). An impact produced in this way can create a shock or vibration even that is transmitted to adjacent storage devices in other test slots, which degrades the isolation scheme of the test rack 100. This problem can be amplified by the high density of the test rack 100, as the test slots can be located in close proximity to one another to conserve space.

In some examples, additional shock or vibration events can be created while the storage device 600 is pushed against or pulled away from one or more electrical connecting elements located in the test slot 500. In order for the storage device 500 to mate or un-mate with the electrical connecting elements, some degree of force (e.g., 45 Newtons) must be exerted on the storage device 600. This force can be greater than the force require to insert the storage device 600 into the test slot 500.

One way to reduce the likelihood of causing shock or vibration events is to use precision automation. As described above, an automated transporter (e.g., the robot 300 (FIG. 3) can be more precise than a human in precisely inserting or removing a storage device with the correct amount of force. In some examples, however, the location of the test slot 500 may change with loading and with temperature, as the isolators associated with the test slot 500 change shape under stress or with temperature. The automated transporter may thus need to be augmented with a camera, laser position sensors, or the like, to sense the location of the frame. These sensors may slow down the operation, and may still be insufficient, as the mounting frame may move in three linear and three rotary dimensions, and it is difficult to measure and compensate for all of these cost-effectively and quickly.

In some examples, a portion of the robot 300 can engage (e.g., grab, pinch, hug, stabilize, attach to, or the like) a frame of the test slot 500 in order to reduce shock and vibration events caused by inserting or removing a storage device. By holding on to the test slot 500, the robot 300 can push or pull the storage device relative to the test slot 500 without moving the test slot 500. Thus, forces exerted on the test slot 500 are transmitted to the robot 300, rather than to the chassis 102 and adjacent storage devices.

Certain features of the test slot 500 or the robot 300 can allow the robot 300 to more easily or more effectively engage the test slot 500. These features can also allow the robot 300 to approximately register relative to the test slot 500, and then engage the test slot 500 while moving it into a precise alignment with the robot 300.

5 FIGs. 10A and 10B illustrate opposite sides of the test slot 500 (only the front portion 500A of the test slot 500 is shown for clarity). The test slot 500 includes sidewalls 502, 504 with engaging elements 506, 508, and 510 mounted thereon. The engaging elements 506, 508, and 510 are configured to assist the robot 300 in temporarily engaging the test slot 500 before, during, or after the insertion or removal of a storage
10 device. The engaging elements 506, 508, and 510 are configured to engage corresponding engaging elements 512, 514 (FIG. 11) located on actuators 516, 518 (FIG. 11) associated with the robot 300. In this example, the engaging elements 512, 514 are recesses in surfaces 513, 515 of the actuators 516, 518.

15 In the example of FIGs. 10A, 10B, 11, and 12, the engaging elements 506, 508, and 510 are kinematic pins that are configured to mate with recesses 512, 514 of actuators 516, 518, respectively. Both of the actuators 516, 518 are associated with the robot. For example, as shown in FIG. 13, the actuators 516, 518 are arranged on opposing sides of the manipulator 312 of the robot 300. As shown in FIGs. 11 and 12, the actuator 516 includes an inner surface 513 that is arranged to face the sidewall 502 of
20 the test slot 500. The inner surface 513 includes the engaging element 512, which in this example is a recess configured to mate with the engaging element 506 (a kinematic pin) when the robot 300 engages the test slot 500. Similarly, the actuator 518 includes an inner surface 515 that includes engaging element 514, which in this example is a v-shaped recess configured to mate with engaging elements 508 and 510 when the robot
25 300 engages the test slot 500. The V-shaped groove and engaging elements 508 and 510 are shaped to form a kinematic connection.

FIG. 13 illustrates an example in which the robot 300 inserts the storage device transporter 400 (which contains storage device 600) into the test slot 500. The actuators 516, 518 are arranged on opposing sides of, and extend outward from, the manipulator
30 312 of the robot 300. Thus, as the robot 300 moves in the direction of the test slot 500,

the actuators 516, 518 protrude in front of the manipulator 312 such that they may contact the test slot 500 before the transporter 400 is inserted into the test slot 500.

In some examples, after the robot 300 extends the manipulator 312 (and the attached actuators 516, 518) toward the test slot 500, the robot 300 may use cameras or
5 other sensors to crudely align the manipulator 312 and actuators 516, 518 with the test slot 500. Once the actuators are in a position to engage the test slot 500 (e.g., by aligning the engaging element 506 with the recess 512 and by aligning the engaging elements 508, 510 with the recess 514), the actuators 516, 518 can “grab” the test slot 500 by causing the actuators 516, 518 to move in directions 520, 522, respectively. While in some
10 examples, this force can be applied pneumatically, hydraulically, or mechanically, the dimensions of the actuators 516, 518 relative to the test slot 500 can be design such that the actuators 516, 518 simply “slip” over the engaging elements.

Once the engaging elements 506, 508, 510 have mated with the recesses 512, 514, an indication can be sent to the robot 300 that the robot 300 has successfully engaged the
15 test slot 500. After this indication has been received, the manipulator 312 can begin to insert the transporter 400 into the test slot 500 by applying force to the transporter 400 in a direction 524. The manipulator 312 may continue to apply force to the transporter 400 until the transporter 400 or storage device 600 has successfully mated with one or more connectors (not shown) located near the distal end 526 of the test slot 500. Again, an
20 indication can be sent to the robot 300 when the transporter and storage device have been successfully inserted into the test slot 500.

By gripping the test slot 500 prior to inserting the transporter 400 into the test slot 500, any impact of the transporter 400 or storage device 600 against a frame of the test slot 500 will not transmit vibration energy to the chassis 102. Instead, because the
25 actuators 516, 518 are engaged with the test slot 500, any shock or vibration energy will be absorbed by the actuators 516, 518, the manipulator 312, and the robot 300. If the robot 300, the manipulator 312, and the actuators 516, 518 are mechanically isolated from the test rack 100, this energy will not be transferred to the test rack 100 or the other storage devices being tested therein.

30 Similar techniques can be used to remove the transporter 400 and/or the storage device 600 from the test slot 500. In that case, the robot 300 first engages the test slot

500 with the actuators 516, 518 to stabilize the test slot 500. Once the actuators 516, 518 have successfully engaged the test slot 500, the manipulator 312 can begin removing the transporter 400 and/or storage device 600 from the test slot 500 (e.g., the manipulator can be engaged the transporter 400, or can begin to remove a transporter 400 with which the manipulator 312 is already interfacing).

While in the examples above there are two actuators 516, 518, any number or type of actuators can be used.

While in the examples above the engagement elements 506, 508, and 510 are described as kinematic pins, other types of engagement elements can be used. For example the engaging elements may be self-aligning, kinematic, non self-aligning, non kinematic, or a combination thereof. Exemplary engagement elements may include pins, pegs, recesses, slots, holes, detents, grooves, friction elements, or magnets. In the case where the engagement elements use friction to engage the test slot, the engagement elements may include one or more friction pads, or one or more textured surfaces of the engagement elements. In some examples, the engagement elements may engage the test slot using a native friction associated with the engagement elements. Similarly, while the actuators 516, 518 have been described as including recesses 512, 514, any suitable engagement element can be used to correspond with the engagement elements of the test slot 500. Moreover, the test slot 500 and the actuators 516, 518 can include any number, shape, size, or type of engagement elements. The test slot can also be engaged in locations on the test slot in addition to or instead of the side walls of the test slot 500. For example, the test slot can be engaged at side and the front, the side and the top, the side and the bottom, the top and the bottom, or any combination thereof.

In some examples, the actuators 516, 518 can engage the test slot 500 after a portion of the storage device 600 or transporter 400 has already been inserted into or removed from the test slot 500. Stated differently, the robot 300 may not use the actuators 516, 518 to “grip” the test slot 500 until at least part of the insertion or removal action has been completed.

In some examples, automated machinery such as the robot 300 (FIG. 1) can be configured to transport storage devices (e.g., disk drives) without the need for a storage device transporter. For example, the robot (or other automated machinery) may directly

contact a storage device in order to transport it to, and deposit it in, a test slot (e.g., test slot 500 (FIG. 4)), without requiring that the storage device be arranged within a storage device transporter.

5 A number of implementations have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the disclosure. For example, the protrusions on the test slots that interface with the isolators in the body could be embodied as protrusions on the body that interface with isolators on the test slots. Accordingly, other implementations are within the scope of the following claims.

WHAT IS CLAIMED IS:

1. A method comprising:
engaging a test slot with automated machinery to inhibit movement of the test
slot, thereby inhibiting transmission of vibration from the test slot to its surroundings; and
while the automated machinery is engaged with the test slot, actuating the
5 automated machinery to:

insert a storage device into the test slot; or
remove the storage device from the test slot.

2. The method of claim 1, wherein the automated machinery engages the test
10 slot with one or more actuators.

3. The method of claim 2, wherein the one or more actuators comprise one or
more first engaging elements.

4. The method of claim 3, wherein the test slot comprises one or more
15 second engaging elements.

5. The method of claim 4, wherein engaging the test slot comprises:
causing the one first engaging elements to temporarily connect to the one or more
20 second engaging elements.

6. The method of claim 3, wherein the one or more first engaging elements
comprise an element selected from a group consisting of:
a pin, a recess, a slot, a magnet, an adhesive, a clasp, and a hook.
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7. The method of claim 3, wherein the one or more of the first engaging
elements are adapted to engage the test slot by friction.

8. The method of claim 4, wherein the one or more second engaging elements comprise an element selected from a group consisting of:

a pin, a recess, a slot, a magnet, an adhesive, a clasp, and a hook.

5 9. The method of claim 2, wherein the automated machinery comprises a robot that comprises a manipulator for carrying the storage device.

10. The method of claim 9, wherein the actuators are coupled to the robot and/or the manipulator.

10 11. The method of claim 1, wherein the storage device is carried by a storage device transporter.

15 12. The method of claim 11, wherein the automated machinery comprises a robot and a manipulator for engaging the storage device transporter; and wherein the actuators are coupled to the robot and/or the manipulator.

13. An apparatus comprising:
at least one engaging element configured to engage a test slot to inhibit movement
20 of the test slot, thereby inhibiting transmission of vibration from the test slot to its surroundings; and

an automated transporter, while the at least one engaging element is engaged with the test slot, configured to:

inserting a storage device into the test slot; or
25 removing the storage device from the test slot.

14. The apparatus of claim 13, wherein the at least engaging element is configured to temporarily connect to one or more second engaging elements of the test slot.

15. The apparatus of claim 13, wherein the at least one engaging element comprises an element selected from a group consisting of:

a pin, a recess, a slot, a magnet, an adhesive, a clasp, and a hook.

5 16. The apparatus of claim 13, wherein the at least one engaging element is adapted to engage the test slot by friction.

17. The apparatus of claim 14, wherein the one or more second engaging elements comprise an element selected from a group consisting of:

10 a pin, a recess, a slot, a magnet, an adhesive, a clasp, and a hook.

18. The apparatus of claim 13, wherein the automated transporter comprises a robot that comprises a manipulator for carrying the storage device;

15 wherein the at least one engaging element is coupled to the robot and/or the manipulator.

19. The apparatus of claim 13 wherein the storage device is carried by the automated transporter.

20. An apparatus comprising:
automated machinery comprising:

means for engaging a test slot to inhibit movement of the test slot, thereby inhibiting transmission of vibration from the test slot to its surroundings; and

means for, while the automated machinery is engaged with the test slot:

25 inserting a storage device into the test slot; or
removing the storage device from the test slot.