United States Patent Application Publication	20250262701
Kind Code	A1
Publication Date	August 21, 2025
Inventor(s)	NAGASAKA; Satoshi et al.

MACHINE TOOL, DIAGNOSTIC TOOL, AND DIAGNOSTIC METHOD

Abstract

A machine tool includes a tool spindle configured to hold a diagnostic tool, a tool transfer apparatus configured to transfer the diagnostic tool, a sensor provided at the diagnostic tool and configured to detect physical quantity that acts on the diagnostic tool when the diagnostic tool is transferred by the tool transfer apparatus, and a diagnostic apparatus configured to determine whether the machine tool has an abnormality based on data indicating the physical quantity detected by the sensor.

Inventors: **NAGASAKA; Satoshi (Niwa-gun, JP), MORI; Yoshinori (Niwa-gun, JP), HORIBE; Kazuya (Niwa-gun, JP), YAMAMOTO; Hiromasa (Niwa-gun, JP), ITO; Masatoshi (Niwa-gun, JP), YATSU; Yuya (Niwa-gun, JP)**

Applicant: **Yamazaki Mazak Corporation** (Niwa-gun, JP)

Family ID: **1000008591965**

Assignee: **Yamazaki Mazak Corporation (Niwa-gun, JP)**

Appl. No.: **19/185249**

Filed: **April 22, 2025**

Related U.S. Application Data

parent WO continuation PCT/JP2022/043881 20221129 PENDING child US 19185249

Publication Classification

Int. Cl.: **B23Q3/155** (20060101)

U.S. Cl.:

CPC **B23Q3/15546** (20130101);

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] The present application is a continuation application of International Application No. PCT/JP2022/043881, filed Nov. 29, 2022. The contents of this application are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION
Field of the Invention
[0002] The present invention relates to a machine tool, a diagnostic tool, and a diagnostic method.
Discussion of the Background
[0003] A technique for diagnosing a machine tool is known.
[0004] As related techniques, JP 2001-153758 A discloses a tool for spindle testing. The tool for spindle testing illustrated in JP 2001-153758 A includes a dummy tool detachably attached to a spindle of a machine tool. In addition, the dummy tool includes a hammer for beating the dummy tool, a mechanism for driving the hammer, and a detector for detecting vibration of the dummy tool.
SUMMARY OF THE INVENTION
[0005] According to one aspect of the present invention, a machine tool includes a tool spindle configured to hold a diagnostic tool, a tool transfer apparatus configured to transfer the diagnostic tool, a sensor provided at the diagnostic tool and configured to detect physical quantity that acts on the diagnostic tool when the diagnostic tool is transferred by the tool transfer apparatus, and a diagnostic apparatus configured to determine whether the machine tool has an abnormality based on data indicating the physical quantity detected by the sensor.
[0006] According to another aspect of the present invention, a diagnostic tool includes a first portion which a tool spindle of a machine tool is configured to hold, a second portion which a tool transfer apparatus is configured to hold, and a sensor. The tool transfer apparatus is configured to transfer the diagnostic tool. The sensor is configured to detect physical quantity that acts on the diagnostic tool when the diagnostic tool is transferred by the tool transfer apparatus. The diagnostic apparatus is configured to determine whether the machine tool has an abnormality based on the physical quantity detected by the sensor.
[0007] According to the other aspect of the present invention, a diagnostic method includes transferring a diagnostic tool by a tool transfer apparatus. The diagnostic tool is configured to be held by a tool spindle of a machine tool. Physical quantity that acts on the diagnostic tool when the diagnostic tool is transferred by the tool transfer apparatus is detected by a sensor provided at the diagnostic tool. Whether the machine tool has an abnormality based on the physical quantity detected by the sensor is determined.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0008] A more complete appreciation of the present disclosure and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:
[0009] FIG. **1** is a diagram of a machine tool according to a first embodiment, schematically illustrating part of the machine tool;

[0010] FIG. **2** is a schematic illustration of a state in which a tool is attached to a tool spindle;
[0011] FIG. **3** is a schematic illustration of a state in which a diagnostic tool is attached to the tool spindle;
[0012] FIG. **4** is a diagram of the machine tool according to the first embodiment, schematically illustrating part of the machine tool;
[0013] FIG. **5** is a diagram of the machine tool according to the first embodiment, schematically illustrating part of the machine tool;
[0014] FIG. **6** is a schematic illustration of a state in which a diagnostic apparatus diagnoses presence or absence of an abnormality in the machine tool, based on data;
[0015] FIG. **7** is a diagram of the diagnostic tool according to the first embodiment, schematically illustrating the diagnostic tool;
[0016] FIG. **8** is a flowchart of an example of a diagnostic method for the machine tool according to the first embodiment;
[0017] FIG. **9** is a diagram of the machine tool according to the first embodiment, schematically illustrating part of the machine tool;
[0018] FIG. **10** is a diagram of the machine tool according to the first embodiment, schematically illustrating part of the machine tool;
[0019] FIG. **11** is a diagram of a machine tool according to a second embodiment, schematically illustrating the machine tool;
[0020] FIG. **12** is a diagram of the machine tool according to the second embodiment, schematically illustrating the machine tool;
[0021] FIG. **13** is a diagram of the diagnostic tool according to the second embodiment, schematically illustrating the diagnostic tool;
[0022] FIG. **14** is a block diagram of a hardware configuration of the diagnostic apparatus, illustrating an example of the hardware configuration;
[0023] FIG. **15** is a diagram of the machine tool according to the second embodiment, schematically illustrating part of the machine tool;
[0024] FIG. **16** is a diagram of the machine tool according to the second embodiment, schematically illustrating part of the machine tool;
[0025] FIG. **17** is a schematic illustration of a state in which the diagnostic apparatus diagnoses presence or absence of an abnormality in the machine tool, based on first data;
[0026] FIG. **18** is a diagram of the machine tool according to the second embodiment, schematically illustrating part of the machine tool;
[0027] FIG. **19** is a diagram of the machine tool according to the second embodiment, schematically illustrating part of the machine tool;
[0028] FIG. **20** is a schematic illustration of a state in which the diagnostic apparatus diagnoses the presence or absence of the abnormality in the machine tool, based on the first data;
[0029] FIG. **21** is a diagram of data acquired by a sensor, schematically illustrating an example of the data;
[0030] FIG. **22** is a graph obtained by frequency analysis of vibration that acts on the diagnostic tool, schematically illustrating an example of the graph;
[0031] FIG. **23** is a graph obtained by the frequency analysis of the vibration that acts on the diagnostic tool, schematically illustrating an example of the graph;
[0032] FIG. **24** is a diagram of the machine tool according to the second embodiment, schematically illustrating part of the machine tool;
[0033] FIG. **25** is a diagram of the machine tool according to the second embodiment, schematically illustrating part of the machine tool;
[0034] FIG. **26** is a diagram of the machine tool according to the second embodiment, schematically illustrating part of the machine tool;
[0035] FIG. **27** is a diagram of the machine tool according to the second embodiment,

schematically illustrating part of the machine tool;
[0036] FIG. **28** is a diagram of the machine tool according to the second embodiment, schematically illustrating part of the machine tool;
[0037] FIG. **29** is a diagram of the machine tool according to the second embodiment, schematically illustrating part of the machine tool;
[0038] FIG. **30** is a diagram of the machine tool according to the second embodiment, schematically illustrating part of the machine tool;
[0039] FIG. **31** is a diagram of the machine tool according to the second embodiment, schematically illustrating part of the machine tool;
[0040] FIG. **32** is a schematic illustration of a state in which the diagnostic apparatus diagnoses the presence or absence of the abnormality in the machine tool, based on second data;
[0041] FIG. **33** is a diagram of an image displayed on a display device, schematically illustrating an example of the image;
[0042] FIG. **34** is a diagram of an image displayed on the display device, schematically illustrating an example of the image;
[0043] FIG. **35** is a diagram of an image displayed on the display device, schematically illustrating an example of the image;
[0044] FIG. **36** is a schematic illustration of a state in which the diagnostic apparatus and a controller are communicably connected with each other; and
[0045] FIG. **37** is a flowchart of an example of a diagnostic method for the machine tool according to the second embodiment.

DESCRIPTION OF THE EMBODIMENTS

[0046] Hereinafter, a machine tool **100**, a diagnostic tool **9**, and a diagnostic method for the machine tool according to embodiments will be described with reference to the drawings. It is to be noted that in the description of the following embodiments, portions and members having the same function are denoted by the same reference numerals, and the repeated descriptions will be omitted for the portions and members having the same reference numerals.

First Embodiment

[0047] With reference to FIGS. **1** to **10**, a machine tool **100**A, a diagnostic tool **9**A, and a diagnostic method for the machine tool according to the first embodiment will be described. FIG. **1** is a diagram of the machine tool **100**A according to the first embodiment, schematically illustrating part of the machine tool **100**A. FIG. **2** is a schematic illustration of a state in which a tool B is attached to a tool spindle **2**. FIG. **3** is a schematic illustration of a state in which the diagnostic tool **9**A is attached to the tool spindle **2**. FIGS. **4** and **5** are each a diagram of the machine tool **100**A according to the first embodiment, schematically illustrating part of the machine tool **100**A. FIG. **6** is a schematic illustration of a state in which a diagnostic apparatus **8** diagnoses presence or absence of an abnormality in the machine tool, based on data DT. FIG. **7** is a diagram of the diagnostic tool **9**A according to the first embodiment, schematically illustrating the diagnostic tool. FIG. **8** is a flowchart of an example of the diagnostic method for the machine tool according to the first embodiment. FIGS. **9** and **10** are each a diagram of the machine tool **100**A according to the first embodiment, schematically illustrating part of the machine tool **100**A.

Machine Tool **100**A

[0048] As illustrated in FIG. **1**, the machine tool **100**A according to the first embodiment includes the tool spindle **2**, a tool transfer apparatus **3**, and the diagnostic apparatus **8**. The machine tool **100**A may include a tool B. In addition, the machine tool **100**A may include the diagnostic tool **9**A.
[0049] As illustrated in FIG. **2**, the tool spindle **2** is capable of holding the tool B. In an example illustrated in FIG. **2**, the tool spindle **2** includes a rotation body **21**, which is capable of holding the tool B, and a support **23**, which supports the rotation body **21** to be rotatable about a first axis AX**1**.
[0050] As illustrated in FIG. **3**, the tool spindle **2** is capable of holding the diagnostic tool **9**A. In an example illustrated in FIG. **3**, the rotation body **21** of the tool spindle **2** holds the diagnostic tool

9A. In addition, the support **23** supports the rotation body **21**, which holds the diagnostic tool **9**A, to be rotatable about the first axis AX**1**.

[0051] As illustrated in FIGS. **4** and **5**, the tool transfer apparatus **3** is capable of transferring each the tool B and the diagnostic tool **9**A. The tool transfer apparatus **3** is provided separately from the tool spindle **2**. In an example illustrated in FIG. **4**, the tool transfer apparatus **3** includes a holder **31**, which holds the tool B, and a mover **36**, which moves the holder **31**. In an example illustrated in FIG. **5**, the holder **31** holds the diagnostic tool **9**A. Further, the mover **36** moves the holder **31**, which holds the diagnostic tool **9**A.

[0052] As illustrated in FIG. **5**, the diagnostic tool **9**A includes a sensor **91**. The sensor **91** detects physical quantity PV, which acts on the diagnostic tool **9**A. Examples of the physical quantity PV to be detected by the sensor **91** includes acceleration that acts on the diagnostic tool **9**A and vibration that acts on the diagnostic tool **9**A.

[0053] In the example illustrated in FIG. **5**, the sensor **91** detects the physical quantity PV, which acts on the diagnostic tool **9**A (examples including the acceleration that acts on the diagnostic tool **9**A and the vibration that acts on the diagnostic tool **9**A) when the diagnostic tool **9**A is transferred by the tool transfer apparatus **3**.

[0054] It is to be noted that herein, the diagnostic tool **9** being transferred by the tool transfer apparatus **3** includes all processes that the tool transfer apparatus **3** transfers the diagnostic tool **9**. More specifically, the diagnostic tool **9** being transferred by the tool transfer apparatus **3** includes (1) the tool transfer apparatus **3** receiving the diagnostic tool **9** from one component element of the machine tool (for example, one of the tool magazine and the tool spindle). The diagnostic tool **9** being transferred by the tool transfer apparatus **3** includes (2) the tool transfer apparatus **3** moving the diagnostic tool **9** from one component element of the machine tool (for example, one of the tool magazine and the tool spindle) toward the other component element of the machine tool (for example, the other one of the tool magazine and the tool spindle). In addition, the diagnostic tool **9** being transferred by the tool transfer apparatus **3** includes (3) the tool transfer apparatus **3** delivering the diagnostic tool **9** to the other component element of the machine tool (for example, the other one of the tool magazine and the tool spindle).

[0055] As illustrated in FIG. **5**, the diagnostic apparatus **8** receives, from the sensor **91**, data DT indicating the physical quantity PV, which acts on the diagnostic tool **9**A when the diagnostic tool **9**A is transferred by the tool transfer apparatus **3**. It is to be noted that the data DT may be analog data (for example, a sensor signal itself) indicating the physical quantity PV or digital data obtained by processing the analog data indicating the physical quantity PV.

[0056] As illustrated in FIG. **6**, the diagnostic apparatus **8** analyzes the data DT indicating the physical quantity PV, which acts on the diagnostic tool **9**A when the diagnostic tool **9**A is transferred by the tool transfer apparatus **3**, and thus diagnoses presence or absence of an abnormality in the machine tool **100**A. Namely, the diagnostic apparatus **8** is configured to determine whether the machine tool **100**A has an abnormality based on data DT indicating the physical quantity PV detected by the sensor **91**.

[0057] For example, in a case where deviation of the data DT from reference data exceeds an allowable range, the diagnostic apparatus **8** determines the presence of an abnormality in the machine tool **100**A. In addition, in a case where the deviation of the data DT from the reference data falls within the allowable range, the diagnostic apparatus **8** determines the absence of the abnormality in the machine tool **100**A. It is to be noted that the reference data may be set, based on an initial state of the machine tool **100**A (for example, a brand new state of the machine tool **100**A), or may be set, based on a state immediately after maintenance of the machine tool **100**A.

[0058] In the machine tool **100**A in the first embodiment, the data DT indicating the physical quantity PV, which acts on the diagnostic tool **9**A when the diagnostic tool **9**A is transferred by the tool transfer apparatus **3** is analyzed, and thus the presence or absence of an abnormality in the machine tool **100**A is diagnosed. Such a diagnosis enables detection of the abnormality in the machine tool **100**A promptly.

[0059] In addition, in the machine tool **100**A in the first embodiment, the diagnostic tool **9**A is transferred with use of the tool transfer apparatus **3** for transferring the tool B. This eliminates the need to provide a dedicated apparatus for transferring the diagnostic tool **9**A. Further, the diagnostic tool **9**A moves along a path similar to the path in which the tool B is transferred by the tool transfer apparatus **3**. Thus, in a figurative sense, by using the diagnostic tool **9**A, the diagnostic apparatus **8** is capable of detecting the state of the machine tool when viewed from a tool transferred by the tool transfer apparatus **3**.

Diagnostic Tool **9**A

[0060] As illustrated in FIG. **5**, the diagnostic tool **9**A in the first embodiment is a diagnostic tool transferred by the tool transfer apparatus **3** of the machine tool **100**A in order to detect the presence or absence of an abnormality in the machine tool **100**A.

[0061] As illustrated in FIG. **7**, the diagnostic tool **9**A includes a first portion **93**, a second portion **94**, the sensor **91**, and a transmission circuit **95**.

[0062] As illustrated in FIG. **3**, the first portion **93** is held by the tool spindle **2** (more specifically, the rotation body **21**) of the machine tool **100**A.

[0063] As illustrated in FIG. **5**, the second portion **94** is held by the tool transfer apparatus **3** (more specifically, the holder **31**).

[0064] The sensor **91** detects the physical quantity PV, which acts on the diagnostic tool **9**A (examples including the acceleration that acts on the diagnostic tool **9**A and the vibration that acts on the diagnostic tool **9**A) when the diagnostic tool **9**A is transferred by the tool transfer apparatus **3**.

[0065] The transmission circuit **95** transmits the data DT indicating the physical quantity PV, which acts on the diagnostic tool **9**A when the diagnostic tool **9**A is transferred by the tool transfer apparatus **3**, to the diagnostic apparatus **8** of the machine tool. The transmission circuit **95** may transmit the data DT indicating the physical quantity PV, which acts on the diagnostic tool **9**A when the diagnostic tool **9**A is transferred by the tool transfer apparatus **3**, to the diagnostic apparatus **8** of the machine tool in real time.

[0066] Alternatively or additionally, as illustrated in FIG. **7**, the diagnostic tool **9**A may include a memory **97**, which stores the data DT. The memory **97** stores the data DT indicating the physical quantity PV, which acts on the diagnostic tool **9**A when the diagnostic tool **9**A is transferred by the tool transfer apparatus **3**. In this case, the diagnostic apparatus **8** receives the data DT directly or indirectly from the memory **97**, and analyzes the received data DT.

[0067] The diagnostic tool **9**A in the first embodiment detects the data DT indicating the physical quantity PV, which acts on the diagnostic tool **9**A when the diagnostic tool **9**A is transferred by the tool transfer apparatus **3**. The diagnostic apparatus **8** diagnoses the presence or absence of an abnormality in the machine tool **100**A, based on the data DT. In this manner, the abnormality in the machine tool **100**A is detected promptly.

[0068] In addition, the diagnostic tool **9**A in the first embodiment is transferred with use of the tool transfer apparatus **3** for transferring the tool B. This eliminates the need to provide a dedicated apparatus for transferring the diagnostic tool **9**A. Further, the diagnostic tool **9**A moves along a path similar to the path along in which the tool B is transferred by the tool transfer apparatus **3**. Thus, in a figurative sense, by detecting the physical quantity that acts on the diagnostic tool **9**A itself, the diagnostic tool **9**A is capable of detecting the state of the machine tool when viewed from the tool transferred by the tool transfer apparatus **3**.

Diagnostic Method for Machine Tool **100**A

[0069] A diagnostic method for the machine tool **100**A in the first embodiment will be described with reference to FIGS. **1** to **10**.

[0070] As illustrated in FIG. **7**, in a first step ST**1**, the diagnostic tool **9**A, which includes the sensor **91**, is prepared. The first step ST**1** is a preparation step. The diagnostic tool **9**A, which is prepared in the preparation step, is attachable to the tool spindle **2** (more specifically, the rotation body **21**) (see FIG. **3**)). In addition, the diagnostic tool **9**A, which is prepared in the preparation step, is transferrable by the tool transfer apparatus **3** other than the tool spindle **2** (see FIG. **5**).

[0071] As illustrated in FIG. **5**, in a second step ST**2**, the diagnostic tool **9**A is transferred by the tool transfer apparatus **3**. The second step ST**2** is a transfer step.

[0072] It is to be noted that herein, the transfer step (in other words, the diagnostic tool **9** being transferred by the tool transfer apparatus **3**), includes all processes that the tool transfer apparatus **3** transfers the diagnostic tool **9**. More specifically, the transfer step includes (1) receiving, by the tool transfer apparatus **3**, the diagnostic tool **9** from one component element of the machine tool (for example, one of the tool magazine and the tool spindle). The transfer step includes (2) moving, by the tool transfer apparatus **3**, the diagnostic tool **9** from one component element of the machine tool (for example, one of the tool magazine and the tool spindle) toward the other component element of the machine tool (for example, the other one of the tool magazine and the tool spindle). In addition, the transfer step includes (3) delivering, by the tool transfer apparatus **3**, the diagnostic tool **9** to the other component element of the machine tool (for example, the other one of the tool magazine and the tool spindle).

[0073] As illustrated in FIG. **5**, in a third step ST**3**, the physical quantity PV, which acts on the diagnostic tool **9**A, is detected by the sensor **91**. The third step ST**3** is a detection step. In the detection step, the physical quantity PV (examples including the acceleration that acts on the diagnostic tool **9**A and the vibration that acts on the diagnostic tool **9**A), which acts on the diagnostic tool **9**A when the diagnostic tool **9**A is transferred by the tool transfer apparatus **3**, is detected by the sensor **91**.

[0074] In a fourth step ST**4**, the data DT (for example, analog data or digital data) indicating the above-described physical quantity PV is transmitted to the diagnostic apparatus **8**. The fourth step ST**4** is a data transmission step. In the data transmission step, the data DT indicating the above-described physical quantity PV, which has been detected by the sensor **91**, is transmitted from the diagnostic tool **9**A to the diagnostic apparatus **8**. The diagnostic apparatus **8** stores the received data DT in a memory.

[0075] It is to be noted that in a case where the diagnostic tool **9**A does not have the data transmission function, the fourth step ST**4** is omitted. In this case, the data DT stored in the memory **97** of the diagnostic tool **9**A is extracted later, and the extracted data DT is stored in a memory of the diagnostic apparatus **8**.

[0076] As illustrated in FIGS. **5** and **6**, in a fifth step ST**5**, the presence or absence of an abnormality in the machine tool **100**A is diagnosed. The fifth step ST**5** is a diagnosis step. In the diagnosis step, the presence or absence of the abnormality in the machine tool **100**A is diagnosed, based on the physical quantity PV (examples including the acceleration that acts on the diagnostic tool **9**A and the vibration that acts on the diagnostic tool **9**A), which is detected by the sensor **91** when the diagnostic tool **9**A is transferred by the tool transfer apparatus **3**. More specifically, the diagnostic step includes (1) receiving, by the diagnostic apparatus **8**, the data DT indicating the physical quantity PV, which acts on the diagnostic tool **9**A when the diagnostic tool **9**A is transferred by the tool transfer apparatus **3**, directly or indirectly from the diagnostic tool **9**A, and (2) analyzing, by the diagnostic apparatus **8**, the data DT to diagnose the presence or absence of the abnormality in the machine tool **100**A.

[0077] For example, in a case where the deviation of the data DT, which is received from the sensor **91**, from the reference data exceeds an allowable range, the diagnostic apparatus **8** determines the presence of the abnormality in the machine tool **100**A. For example, in a case where the deviation of the data DT, which is received from the sensor **91**, from the reference data falls within the allowable range, the diagnostic apparatus **8** determines the absence of the abnormality in the machine tool **100**A.

[0078] In the diagnostic method for the machine tool in the first embodiment, the presence or absence of the abnormality in the machine tool **100**A is diagnosed, based on the physical quantity PV, which is detected by the sensor **91** when the machine tool is transferred by the tool transfer apparatus **3**. Such a diagnosis enables detection of the abnormality in the machine tool **100**A promptly.

[0079] In addition, in the diagnostic method for the machine tool in the first embodiment, the diagnostic tool **9**A is transferred with use of the tool transfer apparatus **3** for transferring the tool B. This eliminates the need to provide a dedicated apparatus for transferring the diagnostic tool **9**A. Further, the diagnostic tool **9**A moves along a path similar to the path in which the tool B is transferred by the tool transfer apparatus **3**. Thus, in a figurative sense, it becomes possible to detect the state of the machine tool when viewed from the tool transferred by the tool transfer apparatus **3**, by using the diagnostic tool **9**A.

Any Additional Configuration

[0080] Any additional configuration adoptable in the machine tool **100**A, the diagnostic tool **9**A, and the diagnostic method for the machine tool in the first embodiment will be described with reference to FIGS. **1** to **10**.

[0081] In an example illustrated in FIG. **9** or FIG. **10**, the sensor **91** includes a first sensor **91***a* (for example, an acceleration sensor), which detects at least one of acceleration and vibration that acts on the diagnostic tool **9**A when the diagnostic tool **9**A is transferred between the tool transfer apparatus **3** and the tool spindle **2**.

[0082] In the example illustrated in FIG. **9** or FIG. **10**, when the diagnostic tool **9**A is transferred between the tool transfer apparatus **3** and the tool spindle **2**, the above-described detection step (the third step ST**3**) includes detecting, by the sensor **91**, the physical quantity PV, which acts on the diagnostic tool **9**A (for example, at least one of the acceleration and the vibration that acts on the diagnostic tool **9**A).

[0083] It is to be noted that FIG. **9** illustrates a state in which the diagnostic tool **9**A is transferred from the tool transfer apparatus **3** to the tool spindle **2**. In addition, FIG. **10** illustrates a state in which the diagnostic tool **9**A is transferred from the tool spindle **2** to the tool transfer apparatus **3** (more specifically, the tool transfer apparatus **3** receives the diagnostic tool **9**A from the tool spindle **2**).

[0084] In the example illustrated in FIG. **9** or FIG. **10**, the above-described data transmission step (the fourth step ST**4**) includes transmitting, from the diagnostic tool **9**A to the diagnostic apparatus **8**, the data DT indicating the physical quantity PV, which acts on the diagnostic tool **9**A when the diagnostic tool **9**A is transferred between the tool transfer apparatus **3** and the tool spindle **2**.

[0085] The data DT includes first data DT**1** indicating physical quantity PV (for example, at least one of the acceleration and the vibration that acts on the diagnostic tool **9**A), which is detected by the sensor **91** when the diagnostic tool **9**A is transferred between the tool transfer apparatus **3** and the tool spindle **2**. In the example illustrated in FIG. **9**, the data DT includes first data DT**1-1** indicating the physical quantity PV, which acts on the diagnostic tool **9**A when the diagnostic tool **9**A is transferred from the tool transfer apparatus **3** to the tool spindle **2**. In the example illustrated in FIG. **10**, the data DT includes first data DT**1-2** indicating the physical quantity PV, which acts on the diagnostic tool **9**A when the diagnostic tool **9**A is transferred from the tool spindle **2** to the tool transfer apparatus **3**.

[0086] In the example illustrated in FIG. **9** or FIG. **10**, the above-described diagnostic step (the fifth step ST**5**) includes diagnosing, by the diagnostic apparatus **8**, the presence or absence of an abnormality in the machine tool **100**A, based on the physical quantity PV (for example, at least one of the acceleration and the vibration that acts on the diagnostic tool **9**A), which is detected by the sensor **91** when the diagnostic tool **9**A is transferred between the tool transfer apparatus **3** and the tool spindle **2**.

[0087] More specifically, the diagnostic step (the fifth step ST**5**) includes (1) receiving, by the diagnostic apparatus **8**, from the diagnostic tool **9**A, the first data DT**1** indicating the physical quantity PV, which is detected by the sensor **91** (for example, at least one of the acceleration and the vibration that acts on the diagnostic tool **9**A) when the diagnostic tool **9**A is transferred between the tool transfer apparatus **3** and the tool spindle **2**, and (2) analyzing, by the diagnostic apparatus **8**, the first data DT**1** to diagnose the presence or absence of an abnormality in the machine tool **100**A.

[0088] In the example illustrated in FIG. **9**, the diagnostic step (the fifth step ST**5**) includes (1) receiving, by the diagnostic apparatus **8**, from the diagnostic tool **9**A, the first data DT**1-1** indicating the physical quantity PV (for example, at least one of the acceleration and the vibration that acts on the diagnostic tool **9**A), which is detected by the sensor **91** when the diagnostic tool **9**A is transferred from the tool transfer apparatus **3** to the tool spindle **2**, and (2) analyzing, by the diagnostic apparatus **8**, the first data DT**1-1** to diagnose the presence or absence of the abnormality in the machine tool **100**A.

[0089] In the example illustrated in FIG. **10**, the diagnostic step (the fifth step ST**5**) includes (1) receiving, by the diagnostic apparatus **8**, from the diagnostic tool **9**A, the first data DT**1-2** indicating the physical quantity PV (for example, at least one of the acceleration and the vibration that acts on the diagnostic tool **9**A), which is detected by the sensor **91** when the diagnostic tool **9**A is transferred from the tool spindle **2** to the tool transfer apparatus **3**, and (2) analyzing, by the diagnostic apparatus **8**, the first data DT**1-2** to diagnose the presence or absence of the abnormality in the machine tool **100**A.

[0090] The diagnostic apparatus **8** may determine the presence of the abnormality in the machine tool **100**A, in a case where the first data (DT**1**; DT**1-1**; DT**1-2**) indicates that abnormal acceleration or abnormal vibration has acted on the diagnostic tool **9**A. More specifically, the diagnostic apparatus **8** may determine the presence of the abnormality in the machine tool **100**A, in a case where the first data (DT**1**; DT**1-1**; DT**1-2**) indicates that the acceleration or the vibration that acts on the diagnostic tool **9**A deviates from a preset allowable range. In addition, the diagnostic apparatus **8** may determine the absence of the abnormality in the machine tool **100**A, in a case where the first data (DT**1**; DT**1-1**; DT**1-2**) indicates that the acceleration or the vibration that acts on the diagnostic tool **9**A falls within the preset allowable range.

Second Embodiment

[0091] A machine tool **100**B, a diagnostic tool **9**B, and a diagnostic method for the machine tool in the second embodiment will be described with reference to FIGS. **11** to **37**. FIG. **11** is a diagram of the machine tool **100**B according to the second embodiment, schematically illustrating the machine tool **100**B. FIG. **12** is a diagram of the machine tool **100**B according to the second embodiment, schematically illustrating the machine tool **100**B. FIG. **13** is a diagram of the diagnostic tool **9**B according to the second embodiment, schematically illustrating the diagnostic tool **9**B. FIG. **14** is a block diagram of a hardware configuration of the diagnostic apparatus **8**, illustrating an example of the hardware configuration. FIGS. **15** and **16** are each a diagram of the machine tool **100**B according to the second embodiment, schematically illustrating part of the machine tool **100**B. FIG. **17** is a schematic illustration of a state in which the diagnostic apparatus **8** diagnoses presence or absence of an abnormality in the machine tool, based on first data DT**1**. FIGS. **18** and **19** are each a diagram of the machine tool **100**B according to the second embodiment, schematically illustrating part of the machine tool **100**B. FIG. **20** is a schematic illustration of a state in which the diagnostic apparatus **8** diagnoses the presence or absence of the abnormality in the machine tool, based on the first data DT**1**. FIG. **21** is a diagram of data acquired by a sensor **91**, schematically illustrating an example of the data DT. FIGS. **22** and **23** are each a graph obtained by frequency analysis of vibration that acts on the diagnostic tool **9**B, schematically illustrating an example of the graph. FIGS. **24** to **31** are each a diagram of the machine tool **100**B according to the second embodiment, schematically illustrating part of the machine tool **100**B. FIG. **32** is a schematic illustration of a state in which the diagnostic apparatus **8** diagnoses the presence or absence of the abnormality in the machine tool, based on second data DT**2**. FIGS. **33** to **35** are each a diagram of an image displayed on a display device **84**, schematically illustrating an example of the image. FIG. **36** is a schematic illustration of a state in which the diagnostic apparatus **8** and a controller **5** are communicably connected with each other. FIG. **37** is a flowchart of an example of the diagnostic method for the machine tool according to the second embodiment.

[0092] As illustrated in FIGS. **11** and **12**, the machine tool **100**B in the second embodiment includes: (1) a tool spindle **2**, which is capable of holding a diagnostic tool **9**B including a sensor **91**; (2) a tool transfer apparatus **3**, which is provided separately from the tool spindle **2**, and which is capable of transferring the diagnostic tool **9**B; and (3) a diagnostic apparatus **8**, which receives, from the sensor **91**, data DT indicating physical quantity PV, which acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred by the tool transfer apparatus **3**, and the diagnostic apparatus **8** analyzes the data DT to diagnose presence or absence of an abnormality in the machine tool **100**B. Thus, the machine tool **100**B in the second embodiment exhibits similar effects to those of the machine tool **100**A in the first embodiment.

[0093] The diagnostic tool **9**B in the second embodiment is a diagnostic tool transferred by the tool transfer apparatus **3** of the machine tool **100**B in order to detect the presence or absence of an abnormality in the machine tool **100**B. As illustrated in FIG. **13**, the diagnostic tool **9**B in the second embodiment includes (1) a first portion **93**, which can be held by the tool spindle **2** of the machine tool **100**B, (2) a second portion **94**, which can be held by the tool transfer apparatus **3**, (3) the sensor **91**, which detects physical quantity PV, which acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred by the tool transfer apparatus **3**, and (4) at least one of a transmission circuit **95** and a memory **9**. The transmission circuit **95** transmits the data DT indicating the physical quantity to the diagnostic apparatus **8** of the machine tool **100**B, and the memory **9** stores the data DT indicating the physical quantity PV. Thus, the machine tool **100**B in the second embodiment exhibits similar effects to those of the machine tool **100**A in the first embodiment.

[0094] As illustrated in FIG. **12**, the diagnostic method for the machine tool in the second embodiment includes: (1) a step of preparing the diagnostic tool **9**B including the sensor **91**, which is attachable to the tool spindle **2** of the machine tool **100**B, and which can be transferred by the tool transfer apparatus **3** other than the tool spindle **2**; (2) a step of transferring the diagnostic tool **9**B by the tool transfer apparatus **3**; and (3) a step of detecting, by the sensor **91**, physical quantity PV, which acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred by the tool transfer apparatus **3**, (4) a step of diagnosing the presence or absence of an abnormality in the machine tool **100**B, based on the physical quantity PV, which is detected by the sensor **91** when the diagnostic tool **9**B is transferred by the tool transfer apparatus **3**. Thus, the diagnostic method for the machine tool in the second embodiment exhibits similar effects as those in the diagnostic method for the machine tool in the first embodiment.

Any Additional Configuration

[0095] Any additional configuration adoptable in the machine tool **100**B, the diagnostic tool **9**B, and the diagnostic method for the machine tool in the second embodiment will be described with reference to FIGS. **11** to **37**.

Tool Spindle **2**

[0096] In an example illustrated in FIG. **15**, the tool spindle **2** includes a rotation body **21**, a support **23**, a bearing **24**, and a rotation driver **25**.

[0097] The rotation body **21** is capable of holding a tool B (if necessary, see FIG. **12**). In addition, the rotation body **21** is capable of holding the diagnostic tool **9**B. More specifically, the rotation body **21** is capable of selectively holding the tool B and the diagnostic tool **9**B.

[0098] In the example illustrated in FIG. **15**, the support **23** supports the rotation body **21** to be rotatable about a first axis AX**1**. The bearing **24** is interposed between the rotation body **21** and the support **23**. In other words, the support **23** supports the rotation body **21** to be rotatable via the bearing **24**.

[0099] The rotation driver **25** rotates the rotation body **21** about the first axis AX**1**. The rotation driver **25** includes a motor. More specifically, the rotation driver **25** includes a stator **25***s*, which is fixed to the support **23**, and a rotor **25***r*, which is fixed to the rotation body **21**. When an electric current is supplied to the stator **25***s*, an electromagnetic action between the stator **25***s* and the rotor **25***r* rotates the rotor **25***r* about the first axis AX**1**. Alternatively, the rotation driver **25** may include a motor and a transmission mechanism (examples including a gear and a transmission belt) that transmits the dynamic power of the motor to the rotation body **21**.

Tool Magazine **4**

[0100] In an example illustrated in FIG. **12**, the machine tool **100**B includes a tool magazine **4** (in other words, a tool stocker). The tool magazine **4** is capable of storing a plurality of tools (B**1**, B**2** . . . , etc.). The tool magazine **4** is also capable of storing the diagnostic tool **9**B.

[0101] In an example illustrated in FIG. **11**, the tool magazine **4** includes a plurality of holding portions **41**, which respectively hold a plurality of tools, and a holding portion mover **45**, which moves the plurality of holding portions **41** along a circling orbit OB. At least one of the plurality of holding portions **41** is capable of holding the diagnostic tool **9**B. Each of all the holding portions **41** may be capable of holding the diagnostic tool **9**B.

Automatic Tool Changer **30**

[0102] In the example illustrated in FIG. **12**, the tool transfer apparatus **3** includes an automatic tool changer **30**. The automatic tool changer **30** is capable of exchanging a tool B, which is held by the tool spindle **2** (more specifically, the rotation body **21**) with another tool.

[0103] In the example illustrated in FIG. **12**, the automatic tool changer **30** is capable of exchanging the tool B, which is held by the tool spindle **2** (more specifically, the rotation body **21**), with the diagnostic tool **9**B. More specifically, when the automatic tool changer **30** exchanges the tool B, which is held by the tool spindle **2**, with the diagnostic tool **9**B, the tool spindle **2** holds the diagnostic tool **9**B.

[0104] In addition, the automatic tool changer **30** is capable of exchanging the diagnostic tool **9**B, which is held by the tool spindle **2** (more specifically, the rotation body **21**), with the tool B. More specifically, when the automatic tool changer **30** exchanges the diagnostic tool **9**B, which is held by the tool spindle **2**, with the tool B, the tool spindle **2** holds the tool B.

[0105] In the example illustrated in FIG. **11**, the automatic tool changer **30** includes a tool change arm **32**. The tool change arm **32** functions as a holder **31**, which holds the tool B (or the diagnostic tool **9**B). The tool change arm **32** includes a first arm **32***a* and a second arm **32***b*. In addition, the first arm **32***a* includes a first gripper **33***a*, which is capable of gripping the tool B (or the diagnostic tool **9**B), and the second arm **32***b* includes a second gripper **33***b*, which is capable of gripping the diagnostic tool **9**B (or the tool B). In the example illustrated in FIG. **11**, an angle formed by the first arm **32***a* and the second arm **32***b* is 180 degrees. Alternatively, the angle formed by the first arm **32***a* and the second arm **32***b* may be any angle other than 180 degrees.

[0106] In the example illustrated in FIG. **11**, the automatic tool changer **30** includes: an arm rotation apparatus **35**, which rotates the tool change arm **32** about a second axis AX**2**; and a mover **36**, which linearly moves the tool change arm **32**. In the example illustrated in FIG. **11**, the second axis AX**2** is parallel to the first axis AX**1**. The automatic tool changer **30** may include a rotation shaft **37**, which rotates together with the tool change arm **32** about the second axis AX**2**, and a shaft support portion **38**, which supports the rotation shaft **37** to be rotatable about the second axis AX**2**.

[0107] The mover **36** includes a first mover **36***a*, which moves the tool change arm **32** in a direction perpendicular to the second axis AX**2**. The mover **36** may include a second mover **36***b*, which moves the tool change arm **32** in a direction parallel to the second axis AX**2**. The mover **36** may be capable of moving the tool change arm **32** three-dimensionally.

[0108] In the example illustrated in FIG. **11**, the automatic tool changer **30** transfers the diagnostic tool **9**B (or the tool B) between the tool spindle **2** and the tool magazine **4**. Alternatively, the automatic tool changer **30** may transfer the diagnostic tool **9**B (or the tool B) between the tool spindle **2** and another transfer apparatus (in other words, a relay transfer apparatus). In other words, the tool transfer apparatus **3** may include the automatic tool changer **30** and another transfer apparatus (in other words, the relay transfer apparatus).

Diagnostic Tool **9**B

[0109] In an example illustrated in FIG. **13**, the diagnostic tool **9**B includes the sensor **91**, which detects the physical quantity PV, which acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred by the tool transfer apparatus **3**. In addition, the diagnostic tool **9**B includes a transmission circuit **95**, which transmits the data DT indicating the physical quantity PV (for example, analog data that a sensor signal itself output by the sensor **91** or digital data obtained by processing the analog data), to the diagnostic apparatus **8**. The transmission circuit **95** preferably transmits the data DT indicating the above-described physical quantity PV to the diagnostic apparatus **8** in a wireless manner. The transmission circuit **95** may transmit the data DT indicating the above-described physical quantity PV to the diagnostic apparatus **8** in real time.

[0110] Alternatively or additionally, the diagnostic tool **9**B may include a memory **97**, which stores the data DT indicating the above-described physical quantity PV. In this case, the diagnostic apparatus **8** directly or indirectly receives the data DT from the memory **97**, and analyzes the received data DT.

[0111] The diagnostic tool **9**B may include a reception circuit **96**. The reception circuit **96** receives a sensing start command from the diagnostic apparatus **8** at a timing when the diagnostic tool **9**B is transferred by the tool transfer apparatus **3**. The reception circuit **96** preferably receives the sensing start command from the diagnostic apparatus **8** in a wireless manner. Upon receipt of the sensing start command via the reception circuit **96**, the sensor **91** starts to detect the above-described physical quantity PV. The data DT indicating the above-described physical quantity PV, which has been detected by the sensor **91**, is transmitted to the diagnostic apparatus **8** via the transmission circuit **95**. It is to be noted that the transmission circuit **95** and the reception circuit **96** may be included in one circuit.

[0112] The reception circuit **96** receives a sensing end command from the diagnostic apparatus **8** at a timing after the transfer of the diagnostic tool **9**B by the tool transfer apparatus **3** is completed. Upon receipt of the sensing end command via the reception circuit **96**, the sensor **91** ends the detection of the above-described physical quantity PV.

[0113] The diagnostic tool **9**B may include a battery **98**. The battery **98** supplies the sensor **91** with electric power. The battery **98** also supplies the transmission circuit **95** and/or the reception circuit **96** with electric power. In the example illustrated in FIG. **13**, the battery **98** and the sensor **91** are electrically connected with each other through a conductive wire member **99**.

[0114] Herein, in a direction along the longitudinal direction of the diagnostic tool **9**B, a first direction DR**1** is defined as a direction from a base end portion of the diagnostic tool **9**B toward a tip end portion of the diagnostic tool **9**B. In addition, herein, a second direction DR**2** is defined as a direction opposite to the first direction DR**1**.

[0115] In the example illustrated in FIG. **13**, in a direction along a central axis AT of the diagnostic tool **9**B, the transmission circuit **95** (or the reception circuit **96**) is disposed further in a first direction DR**1** than the first portion **93**, which can be held by the tool spindle **2**. The transmission circuit **95** (or the reception circuit **96**) may be disposed further in the first direction DR**1** than the second portion **94**, which can be held by the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**). The transmission circuit **95** (or the reception circuit **96**) may be disposed in the tip end portion of the diagnostic tool **9**B.

[0116] In the example illustrated in FIG. **13**, in the direction along the central axis AT of the diagnostic tool **9**B, the sensor **91** is disposed further in the first direction DR**1** than the first portion **93**, which can be held by the tool spindle **2**. The sensor **91** may be disposed further in the first direction DR**1** than the second portion **94**, which can be held by the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**). Alternatively, the sensor **91** may be disposed inside the first portion **93**, which can be held by the tool spindle **2**, or inside the second portion **94**, which can be held by the tool transfer apparatus **3**.

[0117] In the example illustrated in FIG. **13**, the first portion **93**, which can be held by the tool spindle **2**, has a tapered shape in which the outer diameter diminishes further in the second direction DR**2**. In the example illustrated in FIG. **13**, the second portion **94**, which can be held by the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**), is disposed further in the first direction DR**1** than the first portion **93**. The second portion **94** may include an annular groove **94***v* to be gripped by the tool change arm **32**.

[0118] The sensor **91** may include a first sensor **91***a*, which detects at least one of the acceleration and the vibration that acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred by the tool transfer apparatus **3** (for example, when the diagnostic tool **9**B is transferred between the tool transfer apparatus **3** and the tool spindle **2**). The first sensor **91***a* is, for example, an acceleration sensor.

[0119] The sensor **91** may include a second sensor **91***b*, which detects an angular velocity that acts on the diagnostic tool **9**B (in other words, a change in attitude of the diagnostic tool **9**B) when the diagnostic tool **9**B is transferred by the tool transfer apparatus **3** (for example, when the diagnostic tool **9**B is transferred between the tool transfer apparatus **3** and the tool spindle **2**).

[0120] In the example illustrated in FIG. **13**, the diagnostic tool **9**B is a dummy tool without a machining unit, in which the machining unit that machines a workpiece is omitted. Alternatively, the diagnostic tool **9**B may be a real tool with a machining unit that machines the workpiece.

Diagnostic Apparatus **8**

[0121] In an example illustrated in FIG. **14**, the diagnostic apparatus **8** includes a memory **82** and a processor **83**. The diagnostic apparatus **8** may include the display device **84** and/or an input device **85**. The input device **85** may be incorporated in the display device **84** (more specifically, the display device **84** may be a display **841**, which is provided with a touch panel in which an input device **85***a* is incorporated). Alternatively or additionally, the diagnostic apparatus **8** may include an input device **85***b* (examples including a button, a switch, a lever, a pointing device, and a keyboard), which is provided separately from the display device **84**.

[0122] Additionally, the diagnostic apparatus **8** may include a communication circuit **86**. The communication circuit **86** receives the above-described data DT from the transmission circuit **95** of the diagnostic tool **9**B. The data DT received by the communication circuit **86** is stored in the memory **82**. The communication circuit **86** may transmit the above-described sensing start command and the above-described sensing end command to the reception circuit **96** of the diagnostic tool **9**B.

[0123] In the example illustrated in FIG. **14**, the memory **82**, the processor **83**, the communication circuit **86**, the display device **84**, and/or the input device **85** are connected with one another through a bus **87**. The processor **83** includes at least one processor **83***a* (for example, at least one CPU).

[0124] The memory **82** is a storage medium to be readable by the processor **83**. The memory **82** may be, for example, a non-volatile or volatile semiconductor memory such as a RAM, a ROM, a flash memory, may be a magnetic disk, or may be a memory of any other type. The memory **82** stores a program **829** (examples including a diagnostic program **829***a* and a display program **829***b*), and data (for example, the above-described data DT received from the diagnostic tool **9**B).

Transfer of Diagnostic Tool **9**B Between Tool Transfer Apparatus **3** and Tool Spindle **2**

[0125] As illustrated in FIGS. **15** and **16**, the diagnostic apparatus **8** receives, from the sensor **91**, the data DT indicating the physical quantity PV, which acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred by the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**). In an example illustrated in FIG. **16**, the above-described data DT includes the first data DT**1** indicating the physical quantity detected by the sensor **91** when the diagnostic tool **9**B is transferred between the tool transfer apparatus **3** and the tool spindle **2**.

[0126] In an example illustrated in FIG. **16**, the data DT (more specifically, the first data DT**1**) includes first acceleration data DA**1** indicating the acceleration that acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred between the automatic tool changer **30** and the tool spindle **2**. Alternatively or additionally, the above-described data DT (more specifically, the first data DT**1**) may include first vibration data DB**1** indicating the vibration that acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred between the automatic tool changer **30** and the tool spindle **2**. It is to be noted that it is possible to calculate the acceleration with time differential of the speed, and it is possible to calculate the speed with time differential of displacement. Hence, the first acceleration data DA**1** is preferably data acquired by the acceleration sensor, but the first acceleration data DA**1** may be data acquired by a speed sensor or a displacement sensor.

[0127] In an example illustrated in FIG. **16**, the diagnostic apparatus **8** analyzes the above-described first acceleration data DA**1** to diagnose the presence or absence of an alignment abnormality between the automatic tool changer **30** and the tool spindle **2**. More specifically, the diagnostic apparatus **8** analyzes the first acceleration data DA**1** to diagnose whether a misalignment amount between the automatic tool changer **30** and the tool spindle **2** exceeds an allowable range.

[0128] Alternatively or additionally, the diagnostic apparatus **8** may analyze the above-described first vibration data DB**1** to diagnose the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**. More specifically, the diagnostic apparatus **8** may analyze the above-described first vibration data DB**1** to diagnose whether the misalignment amount between the automatic tool changer **30** and the tool spindle **2** exceeds the allowable range.

[0129] In an example illustrated in FIG. **15**, a noticeable alignment abnormality is present between the first axis AX**1** of the tool spindle **2** (in other words, the rotation shaft of the rotation body **21**) and the automatic tool changer **30** (in other words, the central axis AT of the diagnostic tool **9**B, which is held by the automatic tool changer **30**). In this case, in an example illustrated in FIG. **16**, the first acceleration data DA**1** is data indicating that abnormal acceleration has acted on the diagnostic tool **9**B. In addition, the first vibration data DB**1** is data indicating that abnormal vibration has acted on the diagnostic tool **9**B.

[0130] In the example illustrated in FIG. **16**, the above-described first acceleration data DA**1** includes data of the acceleration that acts on the diagnostic tool **9**B when the diagnostic tool **9**B is attached to the tool spindle **2**. The above-described first vibration data DB**1** includes data of the vibration that acts on the diagnostic tool **9**B when the diagnostic tool **9**B is attached to the tool spindle **2**.

[0131] In the example illustrated in FIG. **16**, the diagnostic apparatus **8** analyzes the above-described first data DT**1** (more specifically, at least one of the above-described first acceleration data DA**1** and the above-described first vibration data DB**1**) to diagnose the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2** in a direction perpendicular to the longitudinal direction of the diagnostic tool **9**B. More specifically, the diagnostic apparatus **8** analyzes the above-described first data DT**1** to diagnose whether the misalignment amount between the automatic tool changer **30** and the tool spindle **2** in the direction perpendicular to the longitudinal direction of the diagnostic tool **9**B (in other words, the misalignment amount in X-axis direction or Y-axis direction) exceeds an allowable range.

[0132] As illustrated in FIG. **17**, the diagnostic apparatus **8** may compare at least one of the first acceleration data DA**1** and the first vibration data DB**1** with reference data ND**1** stored in the memory **82** to diagnose the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**. For example, in a case where the deviation of the first acceleration data DA**1** (or the first vibration data DB**1**) from the reference data ND**1** exceeds the allowable range, the diagnostic apparatus **8** determines the presence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**. In addition, in a case where the deviation of the first acceleration data DA**1** (or the first vibration data DB**1**) from the reference data ND**1** falls within the allowable range, the diagnostic apparatus **8** determines the absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**.

[0133] Alternatively, AI technology may be used to determine, by the diagnostic apparatus **8**, the presence or absence of the above-described alignment abnormality. For example, (1) machine learning is performed with use of teacher data in which at least one of the acceleration data and the vibration data when the automatic tool changer **30** attaches the diagnostic tool **9**B to the tool spindle **2** is used as input data, and the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2** is used as output data. (2) The learned model obtained by the machine learning is stored in the memory **82** of the diagnostic apparatus **8**. (3) The diagnostic apparatus **8** inputs at least one of the above-described first acceleration data DA**1** and the above-described first vibration data DB**1** into the learned model stored in the memory **82**, and acquires the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**, as the output data.
[0134] In an example illustrated in FIG. **18**, in a direction parallel to the longitudinal direction of the diagnostic tool **9**B, a noticeable alignment abnormality (see a misalignment amount L**1**) is present between the automatic tool changer **30** and the tool spindle **2**. In this case, in an example illustrated in FIG. **19**, the first acceleration data DA**1** is data indicating that the abnormal acceleration has acted on the diagnostic tool **9**B. In addition, the first vibration data DB**1** is data indicating that the abnormal vibration has acted on the diagnostic tool **9**B.
[0135] In the example illustrated in FIG. **19**, the above-described first acceleration data DA**1** includes data of acceleration that acts on the diagnostic tool **9**B when the automatic tool changer **30** (more specifically, the tool change arm **32**) comes into contact with the diagnostic tool **9**B, which is held by the tool spindle **2**. In addition, the above-described first vibration data DB**1** includes data of the vibration that acts on the diagnostic tool **9**B when the automatic tool changer **30** (more specifically, the tool change arm **32**) comes into contact with the diagnostic tool **9**B, which is held by the tool spindle **2**.
[0136] In the example illustrated in FIG. **19**, the diagnostic apparatus **8** analyzes the above-described first data DT**1** (more specifically, at least one of the above-described first acceleration data DA**1** and the above-described first vibration data DB**1**) to diagnose at least the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2** in the direction parallel to the longitudinal direction of the diagnostic tool **9**B. More specifically, the diagnostic apparatus **8** analyzes the above-described first data DT**1** to diagnose whether a misalignment amount between the automatic tool changer **30** and the tool spindle **2** in the direction parallel to the longitudinal direction of the diagnostic tool **9**B (in other words, the misalignment amount in Z-axis direction) exceeds an allowable range.
[0137] As illustrated in FIG. **20**, the diagnostic apparatus **8** may compare at least one of the first acceleration data DA**1** and the first vibration data DB**1** with reference data ND**2**, which is stored in the memory **82**, to diagnose the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**. For example, in a case where the deviation of the first acceleration data DA**1** (or the first vibration data DB**1**) from the reference data ND**2** exceeds an allowable range, the diagnostic apparatus **8** determines the presence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2** in the direction parallel to the longitudinal direction of the diagnostic tool **9**B. In addition, in a case where the deviation of the first acceleration data DA**1** (or the first vibration data DB**1**) from the reference data ND**2** falls within the allowable range, the diagnostic apparatus **8** determines the absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2** in the direction parallel to the longitudinal direction of the diagnostic tool **9**B.
[0138] Alternatively, the AI technology may be used to determine, by the diagnostic apparatus **8**, the presence or absence of the above-described alignment abnormality. For example, (1) machine learning is performed with use of teacher data in which at least one of the acceleration data and the vibration data when the automatic tool changer **30** receives the diagnostic tool **9**B from the tool spindle **2** is used as input data, and the presence or absence of the alignment abnormality between

the automatic tool changer **30** and the tool spindle **2** is used as output data. (2) The learned model obtained by machine learning is stored in the memory **82** of the diagnostic apparatus **8**. (3) The diagnostic apparatus **8** inputs at least one of the above-described first acceleration data DA**1** and the above-described first vibration data DB**1** into the learned model stored in the memory **82**, and acquires the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**, as the output data.

[0139] FIG. **21** illustrates an example of the data DT including the first acceleration data DA**1** (in other words, an example of the data DT including the first acceleration data DA**1** indicating the acceleration that acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred between the automatic tool changer **30** and the tool spindle **2**).

[0140] In the example illustrated in FIG. **21**, the first acceleration data DA**1** includes lateral acceleration data (more specifically, first lateral acceleration data DAx and/or second lateral acceleration data DAy) that is acceleration data of the diagnostic tool **9**B in the direction perpendicular to the longitudinal direction of the diagnostic tool **9**B. The first lateral acceleration data DAx is acceleration data of the diagnostic tool **9**B in a direction along X axis perpendicular to the longitudinal direction of the diagnostic tool **9**B. The second lateral acceleration data DAy is acceleration data of the diagnostic tool **9**B in the direction perpendicular to the longitudinal direction of the diagnostic tool **9**B and along Y axis, which is perpendicular to X axis.

[0141] Alternatively or additionally, the first acceleration data DA**1** may include axial acceleration data DAz, which is acceleration data of the diagnostic tool **9**B in the direction parallel to the longitudinal direction of the diagnostic tool **9**B (in other words, a direction parallel to Z axis).

[0142] The diagnostic apparatus **8** may diagnose the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**, based on at least the above-described lateral acceleration data (the first lateral acceleration data DAx or the second lateral acceleration data DAy). For example, in a case where a peak value of the first lateral acceleration data DAx or a peak value of the second lateral acceleration data DAy when the diagnostic tool **9**B is transferred between the automatic tool changer **30** and the tool spindle **2** exceeds a first threshold TH**1**, the diagnostic apparatus **8** may determine the presence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**. In addition, in a case where both the peak value of the first lateral acceleration data DAx and the peak value of the second lateral acceleration data DAy when the diagnostic tool **9**B is transferred between the automatic tool changer **30** and the tool spindle **2** are equal to or smaller than the first threshold TH**1**, the diagnostic apparatus **8** may determine the absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**.

[0143] Alternatively or additionally, the diagnostic apparatus **8** may diagnose the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**, based on at least the above-described axial acceleration data DAz. For example, in a case where a peak value of the axial acceleration data DAz when the diagnostic tool **9**B is transferred between the automatic tool changer **30** and the tool spindle **2** exceeds a second threshold, the diagnostic apparatus **8** may determine the presence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**.

[0144] Alternatively or additionally, the diagnostic apparatus **8** may analyze the vibration frequency of the diagnostic tool **9**B in the direction parallel to the longitudinal direction of the diagnostic tool **9**B, based on at least one of the above-described first acceleration data DA**1** and the above-described first vibration data DB**1**. FIG. **22** illustrates analysis results of the vibration frequency of the diagnostic tool **9**B in the direction parallel to the longitudinal direction of the diagnostic tool **9**B.

[0145] The diagnostic apparatus **8** may diagnose the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**, based on the analysis results of the vibration frequency.

[0146] In an example illustrated in FIG. **22**, the alignment abnormality between the automatic tool changer **30** and the tool spindle **2** results in vibrations continuous in a time series manner in a frequency band of about 40 Hz. FIG. **23** illustrates the state of the vibrations of the diagnostic tool **9**B after the alignment between the automatic tool changer **30** and the tool spindle **2** has been adjusted. In an example illustrated in FIG. **23**, the vibrations continuous in a time series manner in the frequency band of about 40 Hz are substantially lost. In the examples illustrated in FIGS. **22** and **23**, by analyzing at least the vibration frequency of the diagnostic tool **9**B in the direction parallel to the longitudinal direction of the diagnostic tool **9**B, the diagnostic apparatus **8** is capable of diagnosing the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**.
[0147] In the examples illustrated in FIGS. **15** to **20**, the diagnostic apparatus **8** is capable of promptly detecting the alignment abnormality between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool spindle **2**. For example, it is assumed that the misalignment amount between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool spindle **2** gradually increases due to a temporal change or an environmental change. In this case, before the misalignment amount reaches the one that causes a machine down situation, the diagnostic apparatus **8** is capable of detecting a slight alignment abnormality promptly. In addition, by making a maintenance plan based on a diagnosis result by the diagnostic apparatus **8**, the user of the machine tool is able to avoid the machine down situation.
Detection of Angular Velocity of Diagnostic Tool **9**B
[0148] In an example illustrated in FIG. **26**, the diagnostic apparatus **8** receives, from the sensor **91**, the data DT indicating the physical quantity PV, which acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred by the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**). The above-described data DT may include angular velocity data DC indicating an angular velocity that acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred by the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**).
[0149] FIG. **21** illustrates an example of the data DT including the angular velocity data DC (in other words, an example of the data DT including the angular velocity data DC indicating the angular velocity that acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred by the tool transfer apparatus **3**).
[0150] The angular velocity data DC may include first angular velocity data DCx, which is angular velocity data of the diagnostic tool **9**B around X axis. The angular velocity data DC may include second angular velocity data DCy, which is angular velocity data of the diagnostic tool **9**B around Y axis. In addition, the angular velocity data DC may include third angular velocity data DCz, which is angular velocity data of the diagnostic tool **9**B around the central axis AT of the diagnostic tool **9**B.
[0151] The diagnostic apparatus **8** may diagnose the presence or absence of an abnormality in the tool transfer apparatus **3** (for example, the automatic tool changer **30**), based on at least the above-described angular velocity data DC. For example, the diagnostic apparatus **8** may diagnose a rattling degree between a plurality of component elements that constitute the tool transfer apparatus **3**, based on at least the above-described angular velocity data DC (the first angular velocity data DCx, the second angular velocity data DCy, or the third angular velocity data DCz).
[0152] As illustrated in FIG. **26**, the above-described data DT may include the angular velocity data DC indicating an angular velocity that acts on the diagnostic tool **9**B when the diagnostic tool **9**B is rotated about the second axis AX**2** by the automatic tool changer **30**.
[0153] The diagnostic apparatus **8** may diagnose the presence or absence of the abnormality in the automatic tool changer **30**, based on at least the above-described angular velocity data DC. For example, the diagnostic apparatus **8** may diagnose a rattling degree between the rotation shaft **37**, which rotates together with the tool changing arm **32**, and the shaft support portion **38**, which supports the rotation shaft, based on at least the above-described angular velocity data DC (the first

angular velocity data DCx, the second angular velocity data DCy, or the third angular velocity data DCz).

Transfer of Diagnostic Tool **9**B Between Tool Transfer Apparatus **3** and Tool Magazine **4**

[0154] In an example illustrated in FIG. **30**, the diagnostic apparatus **8** receives, from the sensor **91**, the data DT indicating the physical quantity PV, which acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred by the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**). The data DT includes second data DT**2** indicating the physical quantity PV (for example, at least one of the acceleration and the vibration that acts on the diagnostic tool **9**B), which is detected by the sensor **91** when the diagnostic tool **9**B is transferred between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool magazine **4**. In addition, the diagnostic apparatus **8** analyzes the second data DT**2** to diagnose the presence or absence of the abnormality in the machine tool **100**B. The diagnostic apparatus **8** may analyze the second data DT**2** to diagnose the presence or absence of the alignment abnormality between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool magazine **4** (more specifically, whether the misalignment amount between the automatic tool changer **30** and the tool magazine **4** exceeds an allowable range).

[0155] In the example illustrated in FIG. **30**, the above-described data DT (more specifically, the second data DT**2**) includes second acceleration data DA**2** indicating the acceleration that acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool magazine **4**. Alternatively or additionally, the above-described data DT (more specifically, the second data DT**2**) may include second vibration data DB**2** indicating the vibration that acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool magazine **4**.

[0156] In the example illustrated in FIG. **30**, the diagnostic apparatus **8** analyzes the above-described second acceleration data DA**2** to diagnose the presence or absence of an alignment abnormality between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool magazine **4**. Alternatively or additionally, the diagnostic apparatus **8** may analyze the above-described second vibration data DB**2** to diagnose the presence or absence of the alignment abnormality between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool magazine **4**.

[0157] In the example illustrated in FIG. **30**, the above-described second acceleration data DA**2** includes data of acceleration that acts on the diagnostic tool **9**B when the diagnostic tool **9**B is stored in the tool magazine **4** from the tool transfer apparatus **3**. Alternatively or additionally, the above-described second acceleration data DA**2** may include data of acceleration that acts on the diagnostic tool **9**B when the diagnostic tool **9**B is removed from the tool magazine **4** to the tool transfer apparatus **3**. In the example illustrated in FIG. **30**, the above-described second vibration data DB**2** includes data of vibration that acts on the diagnostic tool **9**B when the diagnostic tool **9**B is stored in the tool magazine **4** from the tool transfer apparatus **3**. Alternatively or additionally, the above-described second vibration data DB**2** may include data of vibration that acts on the diagnostic tool **9**B when the diagnostic tool **9**B is removed from the tool magazine **4** to the tool transfer apparatus **3**.

[0158] As illustrated in FIG. **32**, the diagnostic apparatus **8** may compare at least one of the second acceleration data DA**2** and the second vibration data DB**2** with reference data ND**3** stored in the memory **82** to diagnose the presence or absence of the alignment abnormality between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool magazine **4**. For example, in a case where the deviation of the second acceleration data DA**2** (or the second vibration data DB**2**) from the reference data ND**3** exceeds an allowable range, the diagnostic apparatus **8** determines the presence of the alignment abnormality between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool magazine **4**. In addition, in a case where the deviation of the second acceleration data DA**2** (or the second vibration data DB**2**) from the reference data ND**3** falls within the allowable range, the diagnostic apparatus **8** determines the absence of the alignment abnormality between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool magazine **4**.

[0159] Alternatively, AI technology may be used to determine, by the diagnostic apparatus **8**, the presence or absence of the above-described alignment abnormality. For example, (1) machine learning is performed with use of teacher data in which at least one of the acceleration data and the vibration data when the diagnostic tool **9**B is transferred between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool magazine **4** is used as input data, and the presence or absence of the alignment abnormality between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool spindle **2** is used as output data. (2) The learned model obtained by machine learning is stored in the memory **82** of the diagnostic apparatus **8**. (3) The diagnostic apparatus **8** inputs at least one of the above-described second acceleration data DA**2** and the above-described second vibration data DB**2** into the learned model stored in the memory **82**, and acquires the presence or absence of the alignment abnormality between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool magazine **4**, as the output data.

[0160] FIG. **21** illustrates an example of the data DT including the second acceleration data DA**2** (more specifically, an example of the data DT including the second acceleration data DA**2** indicating the acceleration that acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred between the automatic tool changer **30** and the tool magazine **4**).

[0161] In the example illustrated in FIG. **21**, the second acceleration data DA**2** includes the lateral acceleration data (more specifically, the first lateral acceleration data DAx and/or the second lateral acceleration data DAy), which is acceleration data of the diagnostic tool **9**B in the direction perpendicular to the longitudinal direction of the diagnostic tool **9**B.

[0162] Alternatively or additionally, the second acceleration data DA**2** may include axial acceleration data DAz, which is acceleration data of the diagnostic tool **9**B in the direction parallel to the longitudinal direction of the diagnostic tool **9**B (in other words, a direction parallel to Z axis).

[0163] The diagnostic apparatus **8** may diagnose the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool magazine **4**, based on at least the above-described lateral acceleration data (the first lateral acceleration data DAx or the second lateral acceleration data DAy). For example, in a case where a peak value of the first lateral acceleration data DAx or a peak value of the second lateral acceleration data DAy when the diagnostic tool **9**B is transferred between the automatic tool changer **30** and the tool magazine **4** exceeds a third threshold TH**3**, the diagnostic apparatus **8** may determine the presence of the alignment abnormality between the automatic tool changer **30** and the tool magazine **4**. In addition, in a case where both the peak value of the first lateral acceleration data DAx and the peak value of the second lateral acceleration data DAy when the diagnostic tool **9**B is transferred between the automatic tool changer **30** and the tool magazine **4** is equal to or smaller than the third threshold TH**3**, the diagnostic apparatus **8** may determine the absence of the alignment abnormality between the automatic tool changer **30** and the tool magazine **4**.

[0164] Alternatively or additionally, the diagnostic apparatus **8** may diagnose the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool magazine **4**, based on at least the above-described axial acceleration data DAz. For example, in a case where the peak value of the axial acceleration data DAz when the diagnostic tool **9**B is transferred between the automatic tool changer **30** and the tool magazine **4** exceeds a fourth threshold value, the diagnostic apparatus **8** may determine the presence of the alignment abnormality between the automatic tool changer **30** and the tool magazine **4**.

[0165] Alternatively or additionally, the diagnostic apparatus **8** may analyze the vibration frequency of the diagnostic tool **9**B, based on at least one of the above-described second acceleration data DA**2** and the above-described second vibration data DB**2**. In addition, the diagnostic apparatus **8** may diagnose the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool magazine **4**, based on an analysis result of the vibration frequency.

[0166] In the examples illustrated in FIGS. **30** and **32**, the diagnostic apparatus **8** is capable of detecting the alignment abnormality between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool magazine **4** promptly. For example, it is assumed that the misalignment amount between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool magazine **4** gradually increases due to a temporal change or an environmental change. In this case, before the misalignment amount reaches the one that causes a machine down situation, the diagnostic apparatus **8** is capable of detecting a slight alignment abnormality promptly. In addition, by making a maintenance plan based on a diagnosis result by the diagnostic apparatus **8**, the user of the machine tool is able to avoid the machine down situation.

Execution of Diagnostic Program **829***a*

[0167] The diagnostic apparatus **8** executes the diagnostic program **829***a*, which is stored in the memory **82**, to analyze the data DT indicating the physical quantity that acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred by the tool transfer apparatus **3**. For example, the diagnostic apparatus **8** analyzes the first data DT**1** (for example, at least one of the above-described first acceleration data DA**1** and the above-described first vibration data DB**1**) indicating the above-described physical quantity detected by the sensor **91** when the diagnostic tool **9**B is transferred between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool spindle **2**. Alternatively or additionally, the diagnostic apparatus **8** may analyze the second data DT**2** (for example, at least one of the above-described second acceleration data DA**2** and the above-described second vibration data DB**2**) indicating the physical quantity detected by the sensor **91** when the diagnostic tool **9**B is transferred between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool magazine **4**.

[0168] In addition, by executing the diagnostic program **829***a*, which is stored in the memory **82**, the diagnostic apparatus **8** diagnoses the presence or absence of the abnormality in the machine tool **100**B, based on the above-described analysis result of the data DT. For example, by executing the diagnostic program **829***a*, which is stored in the memory **82**, the diagnostic apparatus **8** diagnoses the presence or absence of the alignment abnormality between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool spindle **2**, based on the above-described analysis result of the first data DT**1**. Alternatively or additionally, by executing the diagnostic program **829***a*, which is stored in the memory **82**, the diagnostic apparatus **8** may diagnose the presence or absence of the alignment abnormality between the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**) and the tool magazine **4**, based on the above-described analysis result of the second data DT**2**.

[0169] By executing the diagnostic program **829***a*, which is stored in the memory **82**, the diagnostic apparatus **8** may calculate a maintenance recommendation timing of the machine tool **100**B, based on a temporal change of the above-described data DT. For example, the diagnostic apparatus **8** may calculate the maintenance recommendation timing of the machine tool **100**B, based on a temporal change of the first data DT**1** indicating the physical quantity detected by the sensor **91** when the diagnostic tool **9**B is transferred between the automatic tool changer **30** and the tool spindle **2**. In addition, the diagnostic apparatus **8** may calculate the maintenance recommendation timing of the machine tool **100**B, based on a temporal change of the second data DT**2** indicating the physical quantity detected by the sensor **91** when the diagnostic tool **9**B is transferred between the automatic tool changer **30** and the tool magazine **4**.

Execution of Display Program **829***b*

[0170] By executing the display program **829***b*, which is stored in the memory **82**, the diagnostic apparatus **8** may display, on the display device **84**, a diagnosis result of the machine tool **100**B by the diagnostic apparatus **8**.

[0171] In an example illustrated in FIG. **33**, by executing the display program **829***b*, which is stored in the memory **82**, the diagnostic apparatus **8** displays the presence or absence of the abnormality in the machine tool **100**B on the display device **84**. The diagnostic apparatus **8** may display, on the display device **84**, a message MG**1** indicating the presence or absence of the alignment abnormality between the tool spindle **2** and the automatic tool changer **30**. Alternatively or additionally, the diagnostic apparatus **8** may display, on the display device **84**, a message MG**2** indicating the presence or absence of the alignment abnormality between the tool magazine **4** and the automatic tool changer **30**.

[0172] In the example illustrated in FIG. **33**, by executing the display program **829***b*, which is stored in the memory **82**, the diagnostic apparatus **8** displays, on the display device **84**, the maintenance recommendation timing (more specifically, a predicted timing when a first alert is to be issued) of the machine tool **100**B. The diagnostic apparatus **8** may calculate the maintenance recommendation timing of the machine tool **100**B, based on the temporal change of the above-described first data DT**1**, and may display information IN**1** indicating the calculated maintenance recommendation timing on the display device **84**. In addition, the diagnostic apparatus **8** may calculate the maintenance recommendation timing of the machine tool **100**B, based on the temporal change of the above-described second data DT**2**, and may display information IN**2** indicating the calculated maintenance recommendation timing on the display device **84**.

[0173] In a case where the deviation of the data DT from the reference data stored in the memory **82** (more specifically, the data DT indicating the physical quantity PV, which acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred by the tool transfer apparatus **3**) exceeds a first allowable range and the deviation falls within a second allowable range, the diagnostic apparatus **8** may display a first alert WA**1** (see FIG. **34**) on the display device **84**. The first alert WA**1** is, for example, an alert that draws the operator's attention (in other words, an alert of a light degree). In a case where the deviation of the data DT from the reference data stored in the memory **82** (more specifically, the data DT indicating the physical quantity PV, which acts on the diagnostic tool **9**B when the diagnostic tool **9**B is transferred by the tool transfer apparatus **3**) exceeds the second allowable range, the diagnostic apparatus **8** may display a second alert WA**2** (see FIG. **35**) on the display device **84**. The second alert WA**2** is, for example, an alert that prompts contact with a machine tool maker or a maintenance dealer (in other words, an alert of a serious degree).

Machine Tool **100**B

[0174] The machine tool **100**B is, for example, a multitasking machine capable of applying a plurality of types of machining to a workpiece. The machine tool **100**B may be a machining center.

[0175] In the example illustrated in FIG. **11**, the machine tool **100**B includes the tool spindle **2**, the tool transfer apparatus **3** (more specifically, the automatic tool changer **30**), and the controller **5**. The machine tool **100**B may include the tool magazine **4** and/or a workpiece support **6**, which supports a workpiece W.

[0176] The tool spindle **2**, the tool transfer apparatus **3**, and the tool magazine **4** have been described, and repeated description of the tool spindle **2**, the tool transfer apparatus **3**, and the tool magazine **4** will be omitted.

[0177] The controller **5** executes a machining program stored in the memory, and generates a control command. In addition, the controller **5** transmits the control command to a plurality of apparatuses to be controlled (for example, the rotation driver **25**, the arm rotation apparatus **35**, the mover **36**, and the holding portion mover **45**). As illustrated in FIG. **14**, the controller **5** may include the above-described diagnostic apparatus **8**. For example, the controller **5** may include the above-described memory **82**, the above-described processor **83** (for example, the processor **83***a*), the above-described display device **84**, the above-described input device **85**, and the above-described communication circuit **86**.

[0178] In the example illustrated in FIG. **14**, the memory **82** may store a machining program **828**. In addition, the processor **83** may execute the machining program **828**, which is stored in the memory **82**, and may generate a control command. Alternatively, the controller **5** may include a second processor different from the processor **83**, and the second processor may execute the machining program. The control command that has been generated by the processor **83** (or the second processor) is transmitted to the plurality of apparatuses to be controlled (for example, the rotation driver **25**, the arm rotation apparatus **35**, the mover **36**, and the holding portion mover **45**).
[0179] Alternatively, the diagnostic apparatus **8** may be configured with a computer different from the controller **5**. In an example illustrated in FIG. **36**, the diagnostic apparatus **8** is communicably connected with the controller **5**. The controller **5** may include: a second memory **52**, which stores a machining program and the like; a second processor **53** (for example, the second processor **53***a*), which executes the machining program and generates a control command; and a second communication circuit **56**, which transmits a control command CR to the plurality of apparatuses to be controlled (for example, the rotation driver **25**, the arm rotation apparatus **35**, the mover **36**, and the holding portion mover **45**). In addition, the controller **5** may include a second input device **55**, which receives an input from the operator, and/or a second display **54**, which displays various types of data.
Diagnostic Method for Machine Tool
[0180] A diagnostic method for the machine tool in the second embodiment will be described with reference to FIGS. **1** to **37**.
[0181] In a first step ST**1**, a diagnostic tool **9** including a sensor **91** is prepared (see FIG. **7** or FIG. **13**). The first step ST**1** is a preparation step. The diagnostic tool **9**, which is prepared in the preparation step is attachable to the tool spindle **2** (more specifically, the rotation body **21** of the tool spindle **2**). In addition, the diagnostic tool **9**, which is prepared in the preparation step, is transferrable by the tool transfer apparatus **3** (for example, the automatic tool changer **30**) other than the tool spindle **2**.
[0182] The diagnostic tool **9**, which is prepared in the preparation step, may be a diagnostic tool **9**A in the first embodiment, may be the diagnostic tool **9**B in the second embodiment, or may be any other diagnostic tool. The diagnostic tool **9**A in the first embodiment and the diagnostic tool **9**B in the second embodiment have been described, and the repeated description of the diagnostic tools (**9**A and **9**B) will be omitted.
[0183] The diagnostic tool **9**, which is prepared in the preparation step, may be stored in the tool magazine **4**.
[0184] In a second step ST**2**, the diagnostic tool **9** is transferred by the tool transfer apparatus **3**. The second step ST**2** is a transfer step. The transfer step may include transferring the diagnostic tool **9** by the automatic tool changer **30**.
[0185] As illustrated in FIGS. **12**, **15**, and **16**, the transfer step may include a first transfer step of transferring the diagnostic tool **9** from the tool magazine **4** to the tool spindle **2**. At least part of the first transfer step is performed with use of the automatic tool changer **30**.
[0186] Alternatively or additionally, as illustrated in FIGS. **24** to **31**, the transfer step may include a second transfer step of transferring the diagnostic tool **9** from the tool spindle **2** to the tool magazine **4**. At least part of the second transfer step is performed with use of the automatic tool changer **30**.
[0187] In a third step ST**3**, the physical quantity PV, which acts on the diagnostic tool **9**, is detected by the sensor **91**. The third step ST**3** is a detection step. In the detection step, the sensor **91** detects the physical quantity PV (examples including the acceleration that acts on the diagnostic tool **9**, the angular velocity that acts on the diagnostic tool **9**, and the vibration that acts on the diagnostic tool **9**), which acts on the diagnostic tool **9** when the diagnostic tool **9** is transferred by the tool transfer apparatus **3**. The physical quantity that acts on the diagnostic tool **9** is detected by the first sensor **91***a* (for example, the acceleration sensor) of the diagnostic tool **9** and/or the second sensor **91***b* (for

example, the angular velocity sensor) of the diagnostic tool **9**.

[0188] Upon receipt of a sensing start command by the diagnostic tool **9** from the diagnostic apparatus **8**, the sensor **91** may start to detect the physical quantity PV. In addition, upon receipt of a sensing end command by the diagnostic tool **9** from the diagnostic apparatus **8**, the sensor **91** may end detecting the physical quantity PV. The diagnostic apparatus **8** may transmit the sensing start command to the diagnostic tool **9**, before the tool transfer apparatus **3** starts to transfer the diagnostic tool **9**. Further, after the tool transfer apparatus **3** ends transferring the diagnostic tool **9**, the diagnostic apparatus **8** may transmit the sensing end command to the diagnostic tool **9**.

[0189] In a fourth step ST**4**, the data DT (for example, analog data or digital data) indicating the above-described physical quantity PV is transmitted to the diagnostic apparatus **8**. The fourth step ST**4** is a data transmission step. In the data transmission step, the data DT indicating the above-described physical quantity PV, which has been detected by the sensor **91**, is transmitted from the sensor **91** to the diagnostic apparatus **8** via the transmission circuit **95**. The diagnostic apparatus **8** stores the received data DT in the memory **82**.

[0190] The transmission circuit **95** may transmit the data DT indicating the physical quantity PV, which has been detected by the sensor **91**, to the diagnostic apparatus **8** in real time.

[0191] Alternatively, after the sensor **91** ends a series of detection of the physical quantity PV, the transmission circuit **95** may transmit the data DT indicating the physical quantity PV to the diagnostic apparatus **8**. For example, the sensor **91** continuously detects the physical quantity PV, which acts on the diagnostic tool **9**, for a period from the reception of the sensing start command to the reception of the sensing end command. The detected physical quantity PV (in other words, the data DT indicating the physical quantity PV) is stored in the memory **97** of the diagnostic tool **9**. In addition, upon receipt of the sensing end command by the diagnostic tool **9**, the transmission circuit **95** transmits the data DT indicating the physical quantity PV, which is stored in the memory **97**, to the diagnostic apparatus **8**.

[0192] It is to be noted that in a case where the diagnostic tool **9** does not include the transmission circuit **95**, the fourth step ST**4** is omitted. In this case, the data DT, which is stored in the memory **97**, will be extracted later. Further, the data DT, which has been extracted from the memory **97** of the diagnostic tool **9**, is stored in the memory **82** of the diagnostic apparatus **8**.

[0193] In a fifth step ST**5**, the presence or absence of an abnormality in the machine tool **100**B is diagnosed. The fifth step ST**5** is a diagnosis step. In the diagnosis step, the presence or absence of the abnormality in the machine tool **100**B is diagnosed, based on the physical quantity PV, which is detected by the sensor **91** (examples including the acceleration that acts on the diagnostic tool **9**, the angular velocity that acts on the diagnostic tool **9**, and the vibration that acts on the diagnostic tool **9**) when the diagnostic tool **9** is transferred by the tool transfer apparatus **3**. More specifically, the diagnosis step includes (1) receiving, by the diagnostic apparatus **8**, the data DT indicating the physical quantity PV, which acts on the diagnostic tool **9** when the diagnostic tool **9** is transferred by the tool transfer apparatus **3**, from the sensor **91** via the transmission circuit **95** or the memory **97**, and (2) analyzing, by the diagnostic apparatus **8**, the data DT to diagnose the presence or absence of the abnormality in the machine tool **100**B. The diagnosis step may include (3) displaying, by the diagnostic apparatus **8**, the presence or absence of the abnormality in the machine tool **100**B on the display device **84**.

[0194] The detection step (the third step ST**3**) may include detecting, by the sensor **91** of the diagnostic tool **9**, the physical quantity PV, which acts on the diagnostic tool **9** (examples including the acceleration that acts on the diagnostic tool **9**, the angular velocity that acts on the diagnostic tool **9**, and the vibration that acts on the diagnostic tool **9**) when the diagnostic tool **9** is transferred between the automatic tool changer **30** and the tool spindle **2**. In addition, (1) the diagnostic step (the fifth step ST**5**) may include (1) receiving, by the diagnostic apparatus **8**, the first data DT**1** (for example, see FIGS. **16** and **19**) indicating the physical quantity PV, which acts on the diagnostic tool **9** when the diagnostic tool **9** is transferred between the automatic tool changer **30** and the tool

spindle **2**, from the sensor **91** via the transmission circuit **95** or the memory **97**, and (2) analyzing, by the diagnostic apparatus **8**, the first data DT**1** to diagnose the presence or absence of the abnormality in the machine tool **100**B.
[0195] In the example illustrated in FIGS. **15** and **16**, the detection step (the third step ST**3**) includes detecting, by the sensor **91** of the diagnostic tool **9**, the physical quantity PV, which acts on the diagnostic tool **9** (examples including the acceleration that acts on the diagnostic tool **9**, the angular velocity that acts on the diagnostic tool **9**, and the vibration that acts on the diagnostic tool **9**) when the diagnostic tool **9** is attached to the tool spindle **2**.
[0196] Further, in the example illustrated in FIG. **16**, the diagnosis step (the fifth step ST**5**) includes (1) receiving, by the diagnostic apparatus **8**, the first data DT**1** indicating the physical quantity PV, which acts on the diagnostic tool **9** when the diagnostic tool **9** is attached to the tool spindle **2**, from the sensor **91** via the transmission circuit **95** or the memory **97**, and (2) analyzing, by the diagnostic apparatus **8**, the first data DT**1** to diagnose the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2** (more specifically, to diagnose whether the misalignment amount between the automatic tool changer **30** and the tool spindle **2** exceeds an allowable range).
[0197] The diagnosis step (the fifth step ST**5**) may include (1) receiving, by the diagnostic apparatus **8**, the first acceleration data DA**1** indicating the acceleration that acts on the diagnostic tool **9** when the diagnostic apparatus **8** is attached to the tool spindle **2**, from the sensor **91**, and (2) analyzing, by the diagnostic apparatus **8**, the first acceleration data DA**1** to diagnose the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**. Alternatively or additionally, the diagnosis step (the fifth step ST**5**) may include (1) receiving, by the diagnostic apparatus **8**, the first vibration data DB**1** indicating the vibration that acts on the diagnostic tool **9** when the diagnostic tool **9** is attached to the tool spindle **2**, from the sensor **91**, and (2) analyzing, by the diagnostic apparatus **8**, the first vibration data DB**1** to diagnose the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**.
[0198] In the examples illustrated in FIGS. **18** and **19**, the detection step (the third step ST**3**) includes detecting, by the sensor **91** of the diagnostic tool **9**, the physical quantity PV, which acts on the diagnostic tool **9** (examples including the acceleration that acts on the diagnostic tool **9**, the angular velocity that acts on the diagnostic tool **9**, and the vibration that acts on the diagnostic tool **9**) when the diagnostic tool **9** is transferred from the tool spindle **2** to the automatic tool changer **30**.
[0199] In the example illustrated in FIG. **19**, (1) the diagnosis step (the fifth step ST**5**) includes receiving, by the diagnostic apparatus **8**, the first data DT**1** indicating the physical quantity PV, which acts on the diagnostic tool **9** when the diagnostic tool **9** is transferred from the tool spindle **2** to the automatic tool changer **30**, from the sensor **91** via the transmission circuit **95** or the memory **97**, and (2) diagnosing, by the diagnostic apparatus **8**, the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2** (more specifically, diagnosing whether the misalignment amount between the automatic tool changer **30** and the tool spindle **2** exceeds an allowable range.
[0200] The diagnosis step (the fifth step ST**5**) may include (1) receiving, by the diagnostic apparatus **8**, the first acceleration data DA**1** indicating the acceleration that acts on the diagnostic tool **9** when the diagnostic tool **9** is transferred from the tool spindle **2** to the automatic tool changer **30**, from the sensor **91**, and (2) analyzing, by the diagnostic apparatus **8**, the first acceleration data DA**1** (see FIG. **21**) to diagnose the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**. Alternatively or additionally, the diagnosis step (the fifth step ST**5**) may include (1) receiving, by the diagnostic apparatus **8**, the first vibration data DB**1** indicating the vibration that acts on the diagnostic tool **9** when the diagnostic tool **9** is transferred from the tool spindle **2** to the automatic tool changer **30**, from the sensor **91**, and (2) analyzing, by the diagnostic apparatus **8**, the first vibration data DB**1** to diagnose the presence or

absence of the alignment abnormality between the automatic tool changer **30** and the tool spindle **2**.
[0201] As illustrated in FIGS. **26** and **27**, the detection step (the third step ST**3**) may include detecting, by the sensor **91** of the diagnostic tool **9**, the physical quantity PV, which acts on the diagnostic tool **9** (examples including the acceleration that acts on the diagnostic tool **9**, the angular velocity that acts on the diagnostic tool **9**, and the vibration that acts on the diagnostic tool **9**) when the automatic tool changer **30** rotates the diagnostic tool **9** about the second axis AX**2**.
[0202] In addition, the diagnosis step (the fifth step ST**5**) may include (1) receiving, by the diagnostic apparatus **8**, third data DT**3** indicating the physical quantity PV, which acts on the diagnostic tool **9** (examples including the acceleration that acts on the diagnostic tool **9**, the angular velocity that acts on the diagnostic tool **9**, and the vibration that acts on the diagnostic tool **9**) when the diagnostic tool **9** is rotated about the second axis AX**2**, from the sensor **91** via the transmission circuit **95** or the memory **97**, and (2) analyzing, by the diagnostic apparatus **8**, the third data DT**3** (see FIG. **21**) to diagnose the presence or absence of the abnormality in the machine tool **100**B (for example, to diagnose, by the diagnostic apparatus **8**, a rattling degree between the rotation shaft **37**, which rotates together with the tool change arm **32**, and the shaft support portion **38**, which supports the rotation shaft **37**).
[0203] As illustrated in FIG. **29**, the detection step (the third step ST**3**) may include detecting, by the sensor **91** of the diagnostic tool **9**, the physical quantity PV, which acts on the diagnostic tool **9** (examples including the acceleration that acts on the diagnostic tool **9**, the angular velocity that acts on the diagnostic tool **9**, and the vibration that acts on the diagnostic tool **9**) when the automatic tool changer **30** moves the diagnostic tool **9** in the direction perpendicular to the second axis AX**2**.
[0204] Further, the diagnosis step (the fifth step ST**5**) may include (1) receiving, by the diagnostic apparatus **8**, fourth data DT**4** indicating the physical quantity PV, which acts on the diagnostic tool **9** (examples including the acceleration that acts on the diagnostic tool **9**, the angular velocity that acts on the diagnostic tool **9**, and the vibration that acts on the diagnostic tool **9**) when the diagnostic tool **9** is moved in the direction perpendicular to the second axis AX**2**, from the sensor **91** via the transmission circuit **95** or the memory **97**, and (2) analyzing, by the diagnostic apparatus **8**, the fourth data DT**4** (see FIG. **21**) to diagnose the presence or absence of the abnormality in the machine tool (for example, the diagnostic apparatus **8** diagnoses a rattling degree between the component elements in the mechanism for linearly moving the tool change arm **32**).
[0205] As illustrated in FIG. **30**, the detection step (the third step ST**3**) may include detecting, by the sensor **91** of the diagnostic tool **9**, the physical quantity PV, which acts on the diagnostic tool **9** (examples including the acceleration that acts on the diagnostic tool **9**, the angular velocity that acts on the diagnostic tool **9**, and the vibration that acts on the diagnostic tool **9**) when the diagnostic tool **9** is transferred between the automatic tool changer **30** and the tool magazine **4**.
[0206] In addition, the diagnostic step (the fifth step ST**5**) may include (1) receiving, by the diagnostic apparatus **8**, the second data DT**2** indicating the physical quantity PV, which acts on the diagnostic tool **9** when the diagnostic tool **9** is transferred between the automatic tool changer **30** and the tool magazine **4**, from the sensor **91** via the transmission circuit **95** or the memory **97**, and (2) analyzing, by the diagnostic apparatus **8**, the second data DT**2** to diagnose the presence or absence of the abnormality in the machine tool (more specifically, the diagnostic apparatus **8** diagnoses the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool magazine **4**).
[0207] The diagnosis step (the fifth step ST**5**) may include (1) receiving, by diagnostic apparatus **8**, the second acceleration data DA**2**, which acts on the diagnostic tool **9** when the diagnostic tool **9** is transferred between the automatic tool changer **30** and the tool magazine **4**, from the sensor **91**, and (2) analyzing, by diagnostic apparatus **8**, the second acceleration data DA**2** (see FIG. **21**) to diagnose the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool magazine **4**. Alternatively or additionally, the diagnosis step (the fifth step ST**5**) may include (1) receiving, by the diagnostic apparatus **8**, the second vibration data DB**2** indicating

the vibration that acts on the diagnostic tool **9** when the diagnostic tool **9** is transferred between the automatic tool changer **30** and the tool magazine **4**, from the sensor **91***a*, and (2) analyzing, by the diagnostic apparatus **8**, the second vibration data DB**2** to diagnose the presence or absence of the alignment abnormality between the automatic tool changer **30** and the tool magazine **4**.

[0208] A diagnosis result of the machine tool **100**B by the diagnostic apparatus **8** may be uploaded to a cloud managed by a machine tool manufacturer or a maintenance dealer.

[0209] In the example illustrated in FIG. **33**, the diagnosis step (the fifth step ST**5**) includes displaying, by diagnostic apparatus **8**, the presence or absence of the abnormality in the machine tool **100**B on the display device **84**. The diagnostic apparatus **8** may display, on the display device **84**, the message MG**1** indicating the presence or absence of the alignment abnormality between the tool spindle **2** and the automatic tool changer **30**. Alternatively or additionally, the diagnostic apparatus **8** may display, on the display device **84**, the message MG**2** indicating the presence or absence of the alignment abnormality between the tool magazine **4** and the automatic tool changer **30**.

[0210] The diagnostic apparatus **8** may display, on the display device **84**, the maintenance recommendation timing (more specifically, the predicted time when the first alert is to be issued) of the machine tool **100**B. The maintenance recommendation timing is calculated by the diagnostic apparatus **8**, based on the temporal change of the above-described data DT.

[0211] The diagnostic apparatus **8** may display, on the display device **84**, the first alert WA**1** (see FIG. **34**), in a case where the deviation of the data DT (more specifically, the data DT indicating the physical quantity PV, which acts on the diagnostic tool **9** when the diagnostic tool **9** is transferred by the tool transfer apparatus **3**) from the reference data stored in the memory **82** exceeds the first allowable range and the deviation falls within the second allowable range. The first alert WA**1** is, for example, an alert that draws the operator's attention. The diagnostic apparatus **8** may display, on the display device **84**, the second alert WA**2** (see FIG. **35**), in a case where the deviation of the data DT (more specifically, the data DT indicating the physical quantity PV, which acts on the diagnostic tool **9** when the diagnostic tool **9** is transferred by the tool transfer apparatus **3**) from the reference data stored in the memory **82** exceeds the second allowable range. The second alert WA**2** is, for example, an alert that prompts contact with a machine tool maker or a maintenance dealer.

[0212] When the alert (for example, the first alert WA**1** or the second alert WA**2**) that notifies the abnormality in the machine tool **100**B is displayed on the display device **84**, the occurrence of such an alert may be automatically notified to the machine tool manufacturer or the maintenance dealer. In this case, the machine tool manufacturer or the maintenance dealer that receives the notification is able to guide the user of the machine tool **100**B future measures.

[0213] The diagnostic method for the machine tool in the second embodiment (more specifically, the above-described second step ST**2** to the above-described fifth step ST**5**) is preferably performed, while a workpiece is not being machined by the machine tool **100**B. The diagnostic method for the machine tool in the second embodiment (more specifically, the above-described second step ST**2** to the above-described fifth step ST**5**) may be performed when the machine tool **100**B starts up. The diagnostic method for the machine tool in the second embodiment (more specifically, the above-described second step ST**2** to the above-described fifth step ST**5**) may be performed, after a first workpiece is machined by the machine tool **100**B and before a next workpiece is machined by the machine tool **100**B. The diagnostic method for the machine tool in the second embodiment (more specifically, the above-described second step ST**2** to the above-described fifth step ST**5**) may be performed every day, may be performed once several days, or may be performed once several tens of days.

[0214] The present invention is not limited to each embodiment or each modification described above. Obviously, each embodiment or each modification can be appropriately modified or changed within the scope of the technical concept of the present invention. In addition, various techniques used in each embodiment or each modification is also applicable to another embodiment

or another modification as long as there is no technical contradiction. Furthermore, any additional configuration in each embodiment or each modification can be appropriately omitted.
[0215] According to the embodiments, it becomes possible to provide a machine tool, a diagnostic tool, and a diagnostic method for the machine tool, which are capable of detecting an abnormality in the machine tool promptly.
[0216] As used herein, the term “comprise” and its variations are intended to mean open-ended terms, not excluding any other elements and/or components that are not recited herein. The same applies to the terms “include”, “have”, and their variations.
[0217] As used herein, a component suffixed with a term such as “member”, “portion”, “part”, “element”, “body”, and “structure” is intended to mean that there is a single such component or a plurality of such components.
[0218] As used herein, ordinal terms such as “first” and “second” are merely used for distinguishing purposes and there is no other intention (such as to connote a particular order) in using ordinal terms. For example, the mere use of “first element” does not connote the existence of “second element”; otherwise, the mere use of “second element” does not connote the existence of “first element”.
[0219] As used herein, approximating language such as “approximately”, “about”, and “substantially” may be applied to modify any quantitative representation that could permissibly vary without a significant change in the final result obtained. All of the quantitative representations recited in the present application shall be construed to be modified by approximating language such as “approximately”, “about”, and “substantially”.
[0220] As used herein, the phrase “at least one of A and B” is intended to be interpreted as “only A”, “only B”, or “both A and B”.
[0221] Obviously, numerous modifications and variations of the present disclosure are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the present disclosure may be practiced otherwise than as specifically described herein.

Claims

1. A machine tool comprising: a tool spindle configured to hold a diagnostic tool; a tool transfer apparatus configured to transfer the diagnostic tool; a sensor provided at the diagnostic tool and configured to detect physical quantity that acts on the diagnostic tool when the diagnostic tool is transferred by the tool transfer apparatus; and a diagnostic apparatus configured to determine whether the machine tool has an abnormality based on data indicating the physical quantity detected by the sensor.
2. The machine tool according to claim 1, wherein the data includes first data indicating physical quantity detected by the sensor when the diagnostic tool is transferred between the tool transfer apparatus and the tool spindle, and wherein the diagnostic apparatus is configured to determine whether the machine tool has the abnormality based on the first data.
3. The machine tool according to claim 1, wherein the tool transfer apparatus includes an automatic tool changer, wherein the data includes at least one of first acceleration data indicating acceleration that acts on the diagnostic tool when the diagnostic tool is transferred between the automatic tool changer and the tool spindle, and first vibration data indicating vibration that acts on the diagnostic tool when the diagnostic tool is transferred between the automatic tool changer and the tool spindle, and wherein the diagnostic apparatus is configured to determine whether there is an alignment abnormality between the automatic tool changer and the tool spindle based on at least one of the first acceleration data and the first vibration data.
4. The machine tool according to claim 3, wherein the first acceleration data includes lateral acceleration data that indicates lateral acceleration in a direction perpendicular to a longitudinal direction of the diagnostic tool, and wherein the diagnostic apparatus is configured to determine

whether there is the alignment abnormality based on at least the lateral acceleration data.

5. The machine tool according to claim 3, wherein the first acceleration data includes axial acceleration data that indicates axial acceleration in a direction parallel to a longitudinal direction of the diagnostic tool, and wherein the diagnostic apparatus is configured to determine whether there is the alignment abnormality based on at least the axial acceleration data.

6. The machine tool according to claim 3, wherein the diagnostic apparatus is configured to analyze a vibration frequency of a vibration of the diagnostic tool in a direction parallel to a longitudinal direction of the diagnostic tool based on at least one of the first acceleration data and the first vibration data, and wherein the diagnostic apparatus is configured to determine whether there is the alignment abnormality based on an analysis result of the vibration frequency.

7. The machine tool according to claim 1, wherein the data includes angular velocity data indicating an angular velocity that acts on the diagnostic tool when the diagnostic tool is transferred by the tool transfer apparatus, and wherein the diagnostic apparatus is configured to determine whether the machine tool has an abnormality based on the angular velocity data.

8. The machine tool according to claim 1, further comprising: a tool magazine, wherein the data includes at least one of second acceleration data indicating acceleration that acts on the diagnostic tool when the diagnostic tool is transferred between the tool transfer apparatus and the tool magazine, and second vibration data indicating vibration that acts on the diagnostic tool when the diagnostic tool is transferred between the tool transfer apparatus and the tool magazine, and wherein the diagnostic apparatus is configured to determine whether there is an alignment abnormality between the tool transfer apparatus and the tool magazine based on at least one of the second acceleration data and the second vibration data.

9. The machine tool according to claim 1, further comprising: a display device, wherein the diagnostic apparatus is configured to calculate a maintenance recommendation timing of the machine tool based on a temporal change of the data, and wherein the diagnostic apparatus is configured to display the maintenance recommendation timing on the display device.

10. The machine tool according to claim 1, further comprising: a display device, wherein the diagnostic apparatus is configured to display a first alert on the display device in a case where deviation of the data from reference data exceeds a first allowable range and falls within a second allowable range, and wherein the diagnostic apparatus is configured to display a second alert on the display device in a case where the deviation of the data from the reference data exceeds the second allowable range.

11. A diagnostic tool comprising: a first portion which a tool spindle of a machine tool is configured to hold; a second portion which a tool transfer apparatus is configured to hold, the tool transfer apparatus being configured to transfer the diagnostic tool; and a sensor configured to detect physical quantity based on which whether the machine tool has an abnormality is configured to be determined and that acts on the diagnostic tool when the diagnostic tool is transferred by the tool transfer apparatus.

12. The diagnostic tool according to claim 11, further comprising: a reception circuit configured to receive a sensing start command from a diagnostic apparatus at a timing when the diagnostic tool is transferred by the tool transfer apparatus, wherein upon receipt of the sensing start command via the reception circuit, the sensor starts to detect the physical quantity.

13. The diagnostic tool according to claim 11, wherein the sensor comprises a first sensor that is configured to detect at least one of acceleration and vibration that act on the diagnostic tool when the diagnostic tool is transferred between the tool transfer apparatus and the tool spindle.

14. The diagnostic tool according to claim 11, wherein the sensor comprises an angular velocity sensor that is configured to detect an angular velocity that acts on the diagnostic tool when the diagnostic tool is transferred by the tool transfer apparatus.

15. A diagnostic method comprising: transferring a diagnostic tool by a tool transfer apparatus, the diagnostic tool being configured to be held by a tool spindle of a machine tool; detecting, by a sensor provided at the diagnostic tool, physical quantity that acts on the diagnostic tool when the diagnostic tool is transferred by the tool transfer apparatus; and determining whether the machine tool has an abnormality based on the physical quantity detected by the sensor.

16. The diagnostic tool according to claim 11, further comprising: a transmission circuit configured to transmit the physical quantity to the diagnostic apparatus.

17. The diagnostic tool according to claim 11, further comprising: a memory configured to store the physical quantity.