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Tool holder having force sensors

Abstract

A tool holder having force sensors includes a first connection portion, a second connection portion, a first sensing portion, a second sensing portion, at least one first force sensor and at least one second force sensor. The first connection portion connects a cutting tool along an axis. The second connection portion connects a spindle along the axis. The first sensing portion having at least one first hole connects the first connection portion along the axis. The second sensing portion having at least one second hole connects the second connection portion and the first sensing portion. The first force sensor disposed in the first hole is to sense a torsional force. The second force sensor disposed in the second hole is to sense a bending force. The first sensing portion has a bending stiffness greater than that of the second sensing portion.

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATION

(1) This application claims the benefits of Taiwan application Serial No. 110149453, filed on Dec. 29, 2021. The entirety of the above-mentioned patent application is incorporated by references herein.

TECHNICAL FIELD

(2) The present disclosure relates a tool holder having force sensors.

BACKGROUND

(3) In order to meet the demands of Industry 4.0 and high-end products (such as aerospace products and automobiles), global machine tool manufacturers have invested massive resources in the research and development of related technologies. Therefore smart machine tools equipped with working status detection, sensing data analysis capabilities, and aging prediction capabilities will be the trend of future developments.

(4) Although the existing machine tool can be equipped with multiple sensors to detect stress situation of the handle of the machine tool. However, these sensors may simultaneously detect multi-axial forces, such as torsional force and bending force, and thus coupling effects of the multi-axial forces may occur. The aforesaid coupling effects cause some sensors to not accurately detect the stress on various parts of the tool holder of the machine tool, which significantly reduces the sensing performance of these sensors.

SUMMARY

(5) In one embodiment of this disclosure, a tool holder having force sensors comprises a first connection portion, a second connection portion, a first sensing portion, a second sensing portion, at least one first force sensor and at least one second force sensor. The first connection portion connects a cutting tool along an axis. The second connection portion is connected to a spindle along the axis. The first sensing portion has at least one first hole and is connected to the first connection portion along the axis. The second sensing portion has at least one second hole and is connected to the second connection portion and the first sensing portion along the axis. The at least one first force sensor is disposed in the at least one first hole and is configured to sense a torsional force. The at least one second force sensor is disposed in the at least one second hole and is configured to sense a bending force. A second bending stiffness of the second sensing portion is less than a first bending stiffness of the first sensing portion.

(6) In another embodiment of this disclosure, a tool holder having force sensors comprises a first connection portion, a second connection portion, a first sensing portion, a second sensing portion, at least one first force sensor and at least one second force sensor. The first connects a cutting tool along an axis. The second connection portion is connected to a spindle along the axis. The first sensing portion has at least one first hole and is connected to the first connection portion along the axis. The second sensing portion has at least one second hole and is connected to the second connection portion and the first sensing portion along the axis. The at least one first force sensor is disposed in the at least one first hole and is configured to sense a torsional force. The at least one second force sensor is disposed in the at least one second hole and is configured to sense a bending force. A first torsional stiffness of the first sensing portion is less than a second torsional stiffness of the second sensing portion.

(7) Further scope of applicability of the present application will become more apparent from the

detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating exemplary embodiments of the disclosure, are given by way of illustration only, since various changes and modifications within the spirit and scope of the disclosure will become apparent to those skilled in the art from this detailed description.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) The present disclosure will become more fully understood from the detailed description given herein below and the accompanying drawings which are given by way of illustration only, and thus are not limitative of the present disclosure.

(2) FIG. **1** is a schematic perspective view of a first embodiment of the tool holder having force sensors in accordance with this disclosure.

(3) FIG. **2**A is a schematic exploded view of the first force sensor of FIG. **1**.

(4) FIG. **2**B is a schematic perspective view of the first force sensor of FIG. **1**.

(5) FIG. **3**A shows schematically the first sensing portion of FIG. **1**.

(6) FIG. **3**B shows schematically the second sensing portion of FIG. **1**.

(7) FIG. **4**A shows schematically the first force sensor of FIG. **3**A.

(8) FIG. **4**B shows schematically the second force sensor of FIG. **3**B.

(9) FIG. **5** is a schematic view of a second embodiment of the tool holder having force sensors in accordance with this disclosure.

(10) FIG. **6**A shows schematically the first sensing portion of FIG. **5**.

(11) FIG. **6**B shows schematically the second sensing portion of FIG. **5**.

(12) FIG. **7**A shows schematically the first force sensor of FIG. **6**A.

(13) FIG. **7**B shows schematically the second force sensor of FIG. **6**B.

DETAILED DESCRIPTION

(14) Below, exemplary embodiments will be described in detail with reference to accompanying drawings, so as to be easily realized by a person having ordinary knowledge in the art. The inventive concept may be embodied in various forms without being limited to the exemplary embodiments set forth herein. Descriptions of well-known parts are omitted for clarity, and like reference numerals refer to like elements throughout.

(15) Referring to FIG. **1**, a first embodiment of the tool holder **1** having force sensors in accordance with this disclosure is schematically shown. In this embodiment, the tool holder **1** having force sensors includes a first connection portion **12**, a second connection portion **11**, a first sensing portion **13**, a second sensing portion **14**, two first force sensors **15**A, **15**A′ and two second force sensors **15**B, **15**B′.

(16) The first connection portion **12** connects a cutting tool C along an axis AX, in which the axis AX is the central axis of the tool holder **1**.

(17) The second connection portion **11** is connected to a spindle of a machine tool (not shown in the figure) along the axis AX.

(18) The first sensing portion **13** connects the first connection portion **12** along the axis AX. In this embodiment, the first sensing portion **13** has two first holes H**1**. The two first force sensors **15**A, **15**A′ are disposed in the two first holes H**1**, respectively.

(19) One end of the second sensing portion **14** connects the second connection portion **11** along the axis AX, while the other end thereof connects the first sensing portion **13** along the axis AX. In this embodiment, the second sensing portion **14** has two second holes H**2**, and the two second force sensors **15**B, **15**B′ are disposed in these two second holes H**2**, respectively. In one embodiment, any of the first force sensors **15**A, **15**A′ and any of the second force sensors **15**B, **15**B′ can be, but not

limited to, a piezoelectric sensor, a crystal sensor, a strain gauge, or any kind of force sensor.
(20) The first sensing portion **13** is a torsional force sensing portion. The two first force sensors **15**A, **15**A′, respectively disposed in their corresponding first holes H**1**, are configured to sense torsional force applied to the tool holder **1**. The second sensing portion **14** is a bending sensing portion. The two second force sensors **15**B, **15**B′, respectively disposed in their corresponding second holes H**2**, are configured to sense bending force applied to the tool holder **1**.
(21) A second bending stiffness of the second sensing portion **14** is less than a first bending stiffness of the first sensing portion **13**. In other words, the first bending stiffness of the first sensing portion **13** is greater than the second bending stiffness of the second sensing portion **14**. The aforesaid first bending stiffness is defined as the bending moment required for the first sensing portion **13** to generate per unit curvature.
(22) Similarly, the aforesaid second bending stiffness is defined as the bending moment required for the second sensing portion **14** to generate per unit curvature. To a beam structure, the aforesaid bending stiffness can be a product of the Young's modulus and the moment of inertia. In addition, a first torsional stiffness of the first sensing portion **13** is less than a second torsional stiffness of the second sensing portion **14**. In other words, the second torsional stiffness of the second sensing portion **14** is greater than the first torsional stiffness of the first sensing portion **13**. The aforesaid first torsional stiffness is defined as the torque required for the first sensing portion **13** to generate per unit angle of twist. Similarly, the aforesaid second torsional stiffness is defined as the torque required for the second sensing portion **14** to generate per unit angle of twist. The aforesaid angle of twist is an angle in radian.
(23) Based on the aforementioned two sensing portions of different stiffness, the present invention reduces the interference to the two first force sensors **15**A, **15**A′ of the first sensing portion **13** when a torsional force is applied to the tool holder **1**. Similarly, any interference to the two second force sensors **15**B, **15**B′ of the second sensing portion **14** is also reduced when a bending force is applied to the tool holder **1**. Thus, in this embodiment with sensing portions of different stiffness, as the torsional force and the bending force are sensed by the first sensing portion **13** and the second sensing portion **14** simultaneously, the coupling effects to the first sensing portion **13** and the second sensing portion **14** can be effectively reduced. Accordingly, the measurement accuracy of the first force sensors **15**A, **15**A′ and the second force sensors **15**B, **15**B′ can be significantly improved.
(24) Referring to FIG. **2**A and FIG. **2**B, an exploded view and an assembled view of the first force sensor **15**A are schematically shown, respectively. As shown in FIG. **2**A, the first force sensor **15**A includes a first sensing element **151**A, a first shell **152**A, an elastic base **153**A and a fixing screw **154**A.
(25) As shown in FIG. **2**A and FIG. **2**B, the first sensing element **151**A is disposed in the elastic base **153**A. The elastic base **153**A is disposed in the first shell **152**A, such that one end of the elastic base **153**A is exposed from the first shell **152**A and the other end of the elastic base **153**A is fixed by the fixing screw **154**A. The first sensing element **151**A that is disposed in the elastic base **153**A, has a first sensing surface S**1**. In this embodiment, the first force sensor **15**A is a piezoelectric sensor, while the first sensing element **151**A is a piezoelectric plate. In another embodiment, the first force sensor **15**A can be a crystal sensor, a strain gauge or one of other existing force sensors. In this embodiment, the first force sensor **15**A′, and the second force sensors **15**B, **15**B′ have identical elements and identical assembling methods of the first force sensor **15**A, so details thereabout would be omitted herein.
(26) The aforesaid embodiments of the force sensors may be considered as exemplars only. These force sensors may be made in various modifications and variations without departing from the scope or spirit of the disclosure.
(27) Referring to FIG. **3**A and FIG. **3**B, the simplified schematic views of the first sensing portion **13** and the second sensing portion **14** of the tool holder **1** of FIG. **1** are shown, respectively. FIG.

4A and FIG. **4**B show simplified schematic views of configuring the first force sensor and the second force sensor, respectively. As shown in FIG. **3**A, the first sensing portion **13** includes two first holes H**1**. As L**1** passes through the two first holes H**1** and is perpendicular to the axis AX at a first intersection point C**1**. Therefore, the two first force sensors **15**A, **15**A′, respectively disposed in the two first holes H**1**, are symmetrically arranged in the first sensing portion **13** with respect to the first intersection point C**1** (referred as the symmetric point by the two first force sensors **15**A, **15**A′).

(28) As shown in FIG. **3**B, the second sensing portion **14** includes two second holes H**2**. The second line L**2** passes through the two second holes H**2** and is perpendicular to the axis AX at a second intersection point C**2**. Therefore, the two second force sensors **15**B, **15**B′, respectively disposed in the two second holes H**2**, are symmetrically arranged in the second sensing portion **14**, with respect to the second intersection point C**2** (referred as the symmetric point by the two second force sensors **15**B, **15**B′), such that the two second force sensors **15**B, **15**B′ are point-symmetrical.

(29) The first sensing portion **13** has a cross section SC with a normal vector N parallel to the axis AX. The first line L**1** forms a first projection P**1** on the cross section SC of the first sensing portion **13**, and the second line L**2** forms a second projection P**2** on the cross section SC of the first sensing portion **13**.

(30) A projection angle θx is formed between the first projection P**1** and the second projection P**2**. In an embodiment of this disclosure, the projection angle θx can be ranged between −45° and +45°. For example, in this embodiment, the projection angle θx between the first projection P**1** and the second projection P**2** is substantially equal to +45°.

(31) The bending force is a force which would applies bending moment to the tool holder **1**. As shown in FIG. **3**B, when a bending moment MX with respect to an axial direction X or a bending moment MY with respect to an axial direction Y applies to the tool holder **1** of this embodiment whose the projection angle θx between the first projection P**1** and the second projection P**2** is substantially equal to +45°, the second sensing elements **151**B, **151**B′ would sense the maximum bending strain and the first sensing elements **151**A, **151**A′ would sense the minimum bending strain at this moment. In details, when a bending moment MX with respect to the axial direction X (or bending moment MY with respect to the axial direction Y) and a torsional force with respect to the axial direction D of the axis AX simultaneously applies to the tool holder **1** of this embodiment, the ratio of bending strain to the first total strain measured by the first sensing elements **151**A, **151**A′ would be minimum. Thus, when the projection angle θx between the first projection P**1** and the second projection P**2** is substantially equal to +45°, the bending strain coupled to the measurement of the first sensing elements **151**A, **151**A′ would be reduced. Thereupon, the coupling effect induced by the several multi-forces (for example, torsional force and bending force) in diffident axes would be reduced.

(32) In another embodiment, the projection angle θx between the first projection P**1** and the second projection P**2** can be substantially equal to −45°. Furthermore, in another embodiment, the projection angle θx can be ranged between −135° and +135°, or be substantially equal to −135° or +135°.

(33) As shown in FIG. **4**A, a first sensing angle θ**1** is formed between the first normal vector N**1** of the first sensing surface S**1** of the first sensing element **151**A,**151**A′ and the axial direction D of the axis AX. In an embodiment of this disclosure, the first sensing angle θ**1** can be ranged between −45° and +45°. For example, in this embodiment, the first sensing angle θ**1** can be substantially equal to +45° or −45°.

(34) In addition, a second sensing angle θ**2** is formed between the second normal vector N**2** of the second sensing surface S**2** of the second sensing element **151**B, **151**B′ and the axial direction D of the axis AX. In an embodiment of this disclosure, the first sensing angle θ**1** is substantially not equal to the second sensing angle θ**2**. In the embodiment shown in FIG. **4**B, the second sensing angle θ**2** can be substantially equal to 0° or 180°. In another embodiment, the second sensing angle

θ**2** may be greater or less than 0°.

(35) As shown in FIG. **3**A, FIG. **3**B, FIG. **4**A and FIG. **4**B, in this embodiment, the first sensing angle θ**1** can be substantially equal to +45° or −45°. Thus, when a torsional force TZ with respect to the axial direction D of an axis AX applies to the tool holder **1**, the normal direction N**1** of the first sensing surface S**1** of the first sensing element **151**A would be regard to the direction for the maximum torsional strain. Thus, when the first sensing angle θ**1** is substantially equal to +45° or −45°, the torsional strain measured by the first sensing element **151**A would be the maximum. Thereupon, when the first force sensor **15**A measures the torsional force TZ, the measurement sensitivity can be effectively improved.

(36) Similarly, when the first sensing angle θ**1** between the first normal vector N**1** of the first sensing surface S**1** of the first sensing element **151**A′ and the axial direction D of an axis AX is +45° or −45°, the direction of the first sensing surface S**1** would be regard to the direction for the maximum torsional strain. As such, the torsional strain measured by the first sensing element **151**A′ would also be maximum. Therefore, when the first force sensor **15**A′ senses the torsional force TZ, the measurement sensitivity can be effectively improved. In addition, since the first force sensor **15**A and the first force sensor **15**A′ are disposed symmetrically with respect to the first intersection point C**1**, thus these two first force sensors **15**A, **15**A′ can sense the forces applied to the entire tool holder **1** to improve the sensing efficiency.

(37) In this embodiment, the second sensing surface S**2** of the second sensing element **151**B, **151**B′ has a second normal vector N**2** parallel to the axial direction D of an axis AX. In other words, the second sensing angle θ**2** formed between the second normal vector N**2** and the axial direction D of an axis AX is substantially equal to 0°. When a bending moment MX with respect to the axial direction X or a bending moment MY with respect to the axial direction Y applies to the tool holder **1** of this embodiment, the direction of the second sensing surface S**2** of the second sensing element **151**B, **151**B′ would be regard to the direction for the maximum bending strain. Hence, when the two second force sensors **15**B, **15**B′ is used to measure the bending moments MX with respect to the axial direction X or the bending moments MY with respect to the axial direction Y, the measurement sensitivity of the second sensing element **151**B, **151**B′ can be improved. In addition, since these two second force sensors **15**B, **15**B′ are disposed symmetrically with respect to the second intersection point C**2**, thus these two second force sensors **15**B, **15**B′ would sense the forces applied to the entire tool holder **1** to improve the sensing efficiency.

(38) In this embodiment, since the projection angle θx between the first projection P**1** and the second projection P**2** can be substantially equal to +45°, the direction of the first sensing surface S**1** of each of the first force sensors **15**A, **15**A′ would be regard to the direction for the maximum torsional strain, and the direction of each of the second sensing surface S**2** of the second force sensors **15**B, **15**B′ would be regard to the direction for the maximum bending strain. More precisely, when a torsional force TZ applies to the tool holder **1**, the first torsional force measurement of the two first force sensors **15**A, **15**A′ would be larger than the second torsional force measurement of the two second force sensors **15**B, **15**B′. When a bending moment MX with respect to the axial direction X or a bending moment MY with respect to an axial direction Y applies to the tool holder **1**, the first bending measurement of the two first force sensors **15**A, **15**A′ would be smaller than the second bending measurement of the second force sensors **15**B, **15**B′. Thus, when the projection angle θx between the first projection P**1** and the second projection P**2** is substantially equal to +45°, the coupling effect to the first force sensors **15**A, **15**A′ and the second force sensors **15**B, **15**B′ can be further reduced. In order to effectively measure the multi-forces applied on the tool holder **1**, when the first force sensors **15**A, **15**A′ are disposed in the corresponding first holes H**1**, and the second force sensors **15**B, **15**B′ are disposed in the corresponding second holes H**2**, the foresaid first sensing angle θ**1** and second sensing angle θ**2** can be adjusted accordingly.

(39) In this disclosure, at least one display device (not shown in the figure) can be used to show the

measured torsional force and measured bending moment of the two first force sensors **15**A, **15**A′ and the two second force sensors **15**B, **15**B′. In addition, through wireless communication, the first force sensors **15**A, **15**A′ and the second force sensors **15**B, **15**B′ can transmit the measured data in real time to a data processing platform in a mobile device such as a tablet computer, a mobile phone or a notebook computer.

(40) In addition, quantities of the force sensors **15**A, **15**A′ and quantities of the second force sensors **15**B, **15**B′ can be increased or decreased in accordance with practical requirements. For example, in another embodiment, the first sensing portion **13** can have only one first force sensor **15**A for sensing the torsional force TZ while the cutting tool rotates clockwise or counter clockwise.

(41) Referring to FIG. **5**, a schematic view of a second embodiment of the tool holder **2** having force sensors in accordance with this disclosure is shown. In this embodiment, the tool holder **2** having force sensors includes a first connection portion **22**, a second connection portion **21**, a first sensing portion **23**, a second sensing portion **24**, two first force sensors **25**A, **25**A′ and four second force sensors **25**B, **25**B′, **25**B″, **25**B‴.

(42) The first connection portion **22** connects a cutting tool C along an axis AX, in which the axis AX is the central axis of the tool holder **2**. The second connection portion **21** is connected to a spindle (not shown in the figure) along the axis AX of the tool holder **2**. The first sensing portion **23** connects the first connection portion **22** along the axis AX. The first sensing portion **23** has two first holes H**1** and the two first force sensors **25**A, **25**A′ are disposed in the two first holes H**1** respectively. One end of the second sensing portion **24** connects the second connection portion **21** along the axis AX, while another end thereof connects the first sensing portion **23** along the axis AX. Different from the aforesaid embodiments, the second sensing portion **24** of the present embodiment has four second holes H**2**, and four second force sensors **25**B, **25**B′, **25**B″, **25**B‴ are disposed in the four second holes H**2** respectively. Comparing with the aforesaid first embodiment, the second sensing portion **24** of the present embodiment has more second force sensors **25**B, **25**B′, **25**B″, **25**B‴.

(43) Similarly, the first sensing portion **23** is a torsional force sensing portion. The two first force sensors **25**A, **25**A′, disposed inside the two first holes H**1**, are configured to sense torsional force applied to the tool holder **2**. The second sensing portion **14** is a bending force sensing portion. The four second force sensors **25**B, **25**B′, **25**B″, **25**B‴, respectively disposed in the four second holes H**2**, are configured to sense bending force applied to the tool holder **2**. A first bending stiffness of the first sensing portion **23** is greater than a second bending stiffness of the second sensing portion **24**, and first torsional stiffness of the first sensing portion **23** is less than a second torsional stiffness of the second sensing portion **24**. Thus, when a torsional force applies to the tool holder **2**, the first force sensors **25**A, **25**A′ can sense larger torsional strains than that measured by the second force sensors **25**B, **25**B′, **25**B″, **25**B‴. Also, when a bending force applies to the tool holder **2**, the second force sensors **25**B, **25**B′, **25**B″, **25**B‴ can sense larger bending strains than that measured by the first force sensors **25**A, **25**A′. Therefore, when a torsional force applies to the tool holder **2**, the first force sensors **25**A, **25**A′ can have better measurement sensitivity. And, when a bending force applies to the tool holder **2**, the second force sensors **25**B, **25**B′, **25**B″, **25**B‴ can have better measurement sensitivity.

(44) More precisely, since tool holder **2** of this embodiment has two sensing portions with different stiffness, thus, when a torsional force and a bending force simultaneously apply on the tool holder **2**, the first force sensors **25**A, **25**A′ would sense a first total strain, which includes a first torsional strain and a first bending strain. Since the first sensing portion **23** has a smaller first torsional stiffness and a larger first bending stiffness, thus, a ratio of the first torsional strain to the first total strain would be greater than a ratio of the first bending strain to the first total strain. Thereupon, the coupling effect to the first total strain can be reduced. Furthermore, when the first sensing portion **23** has a smaller first torsional stiffness and a larger first bending stiffness, the first sensing portion

23 can measure the torsional force more accurately.

(45) On the other hand, when a torsional force and a bending force simultaneously apply on the tool holder **2**, the second force sensors **25**B, **25**B′, **25**B″, **25**B‴ would sense a second total strain, which includes a second torsional strain and a second bending strain. Since the second sensing portion **24** has a larger second stiffness and a smaller second bending stiffness, thus a ratio of the second torsional strain to the second total strain would be smaller than a ratio of the second bending strain to the second total strain. Therefore, the coupling effect in the second total strain can be reduced. Furthermore, when the second sensing portion **24** has a smaller second bending stiffness and a larger second torsional stiffness, the second sensing portion **24** can measure the bending force more accurately.

(46) Referring to FIG. **6**A and FIG. **6**B, two simplified views of the first sensing portion **23** and the second sensing portion **24** of a second embodiment of the tool holder **2** are schematically shown, respectively. Also, in the embodiments of FIG. **7**A and FIG. **7**B, arrangements of the first force sensors and the second force sensors are schematically shown, respectively. As shown in FIG. **6**A and FIG. **6**B, the first sensing portion **23** includes two first holes H**1**, and a first line L**1** passing through the two first holes H**1** is intersected with the axis AX at a third intersection point C**3**. Therefore, the third intersection point C**3** is referred as a symmetry point for disposing the two first force sensors **25**A, **25**A′ in the two first holes H**1**, such that the two first force sensors **25**A, **25**A′ are arranged symmetrically with respect to the third intersection point C**3**.

(47) The second sensing portion **24** has four second holes H**2**. A second line L**2** passes through two of these four second holes H**2** and a third line L**3** passes through the other two of these four second holes H**2**. The second line L**2** and the third line are both intersected with the axis AX at a same fourth intersection point C**4**, in which an angle between the second line L**2** and the third line L**3** is 90°. Thus, the two second force sensors **25**B, **25**B′ are disposed respectively inside the two second holes H**2** passed by the second line L**2**, and are arranged symmetrically with respect to the fourth intersection point C**4**, such that the two second force sensors **25**B, **25**B′ are point-symmetrical. In addition, the other two second force sensors **25**B″, **25**B‴ are disposed inside the other second holes H**2** passed by the third line L**3**, and are arranged symmetrically with respect to the fourth intersection point C**4**, such that the two second force sensors **25**B″, **25**B‴ are point symmetrical.

(48) The first sensing portion **23** has a cross section SC with a normal vector N parallel to the axial direction D of the axis AX. The first line L**1** in FIG. **6**A passing through the first holes H**1** forms a first projection P**1** on the cross section SC. The second line L**2** in FIG. **6**B and the third line L**3** in FIG. **6**B passing the second holes H**2** form a second projection P**2** and a third projection P**3** on the cross section SC, respectively.

(49) A projection angle θx**1** is formed between the first projection P**1** and the second projection P**2**, and a projection angle θx**2** is formed between the first projection P**1** and the third projection P**3**. In an embodiment, each of the projection angle θx**1** and the projection angle θx**2** can be an angle between −45° and +45°. In this embodiment, the projection angle θx**1** can be substantially equal to +45°, while the projection angle θx**2** can be substantially equal to −45°.

(50) As shown in FIG. **6**B, when a bending moment MX with respect to an axial direction X or another bending moment MY with respect to another axial direction Y applies to the tool holder **2** of this embodiment, and when the projection angle θx**1** between the first projection P**1** and the second projection P**2** is substantially equal to +45°, the second sensing elements **251**B, **251**B′, **251**B″, **251**B‴ would sense the maximum bending strain, and the first sensing elements **251**A, **251**A′ would sense the minimum bending strain. In further detailed, when a bending force with respect to the axial direction X (or with respect to the axial direction Y) and a torsional force with respect to the axial direction D of an axis AX applies to the tool holder **2** of this embodiment, the ratio of bending strain to the first total strain measured by the first sensing elements **251**A, **251**A′ would be minimal. Thus, when the projection angle θx**1** between the first projection P**1** and the second projection P**2** can be substantially equal to +45°, the bending strains which are coupled to

first total strain measured by the first sensing elements **251**A, **251**A′, would be reduced. Thereupon, when the tool holder **2** simultaneously measures the multi-forces in several axes (for example, torsional force and bending force), the coupling effect would be reduced.

(51) In another embodiment, each of the projection angle θx**1** and the projection angle θx**2** can be an angle between −135° and +135°. For example, the projection angle θx**1** and the projection angle θx**2** can be substantially equal to −135° or +135°, respectively.

(52) Refer now to FIG. **2**A, FIG. **2**B, FIG. **5**A, FIG. **5**B, FIG. **7**A and FIG. **7**B at the same time. In this embodiment, since each of the first force sensors **25**A, **25**A′ and each of the second force sensors **25**B, **25**B′, **25**B″, **25**B‴ are the same as first force sensor **15**A of the aforesaid embodiment, thus each of the first force sensors **25**A, **25**A′ and each of the second force sensors **25**B, **25**B′, **25**B″, **25**B‴ can be represented by the sensor shown in FIG. **2**A and FIG. **2**B. The first force sensor **25**A includes a first sensing element **251**A which is represented by a first sensing element **151**A shown in FIG. **2**A and has a first sensing surface S**1** shown in FIG. **7**A. The second force sensor **25**B includes a second sensing element **251**B which is also represented by a first sensing element **151**A shown in FIG. **2**A and has a second sensing surface S**2** shown in FIG. **7**B. As shown in FIG. **7**A and FIG. **7**B, A first sensing angle θ**1** is formed between a first normal vector N**1** of the first sensing surface S**1** of the first sensing element **251**A and an axial direction D of the axis AX. In this embodiment, the first sensing angle θ**1** can be substantially equal to −45° or +45°. Similar to the first embodiment, when the first sensing angle θ**1** of this embodiment is substantially equal −45° or +45°, the first sensing element **251**A would senses a maximum torsional strain. Therefore, when the first force sensor **25**A measures the torsional force TZ, the measurement sensitivity can be improved. Since the first force sensor **25**A′ and the first force sensor **25**A are identical thus details about the first force sensor **25**A′ would be omitted herein. In addition, as shown in FIG. **7**B, a second sensing angle θ**2** is formed between a second normal vector N**2** of the second sensing surface S**2** of the second sensing element **251**B and the axial direction D of the axis AX. The first sensing angle θ**1** is substantially not equal to the second sensing angle θ**2**. Similar to the first embodiment, the second sensing angle θ**2** of this embodiment can be substantially equal to 0°. When a bending moment MX with respect to an axial direction X or a bending moment MY with respect to an axial direction Y applies to the tool holder **2** of this embodiment, the second sensing element **251**B senses the maximum bending strain. Hence, while the second force sensor **25**B measures the bending moment MX with respect to an axial direction X or the bending moment MY with respect to an axial direction Y, the measurement sensitivity can be effectively improved. Since the second force sensors **25**B′, **25**B″, **25**B‴ and the second force sensor **25**B are identical, thus details about **25**B′, **25**B″, **25**B‴ would be omitted herein.

(53) In summary, according to the aforesaid embodiments of the disclosure, the tool holder having force sensors has sensing portions with different stiffness and an active sensing mechanism. Thus, the first force sensors of the first sensing portion can sense the torsional force applied to the tool holder and minimize the interference induced by the bending force applied to the tool holder. Similarly, the second force sensors of the second sensing portion can sense the bending force applied to the tool holder and minimize the interference induced by the torsional force applied to the tool holder. In this disclosure, when the first force sensors measure the torsional force, the tool holder has sensing portions with different stiffness can minimize the ratio of bending strain to the first total strain measured by the first sensing elements. And when the second force sensors measure the bending force, the tool holder has sensing portions with different stiffness can minimize the ratio of the second torsional strain to the second total strain measured by the second sensing elements. Thereupon, according to the embodiments of the tool holder having force sensors in this disclosure, the coupling effect can be effectively reduced and the measurement accuracy of the first force sensors and the second force sensors can be improved when the tool holder measures torsional force and bending force simultaneously.

(54) In addition, according to the embodiments of this disclosure, the direction of the sensing

surface for each of the sensors of the tool holder having force sensors can be adjusted to the direction for the maximum torsional force or the direction for the maximum bending force. By this way, when each of the sensors measures the torsional force or bending force, the measurement sensitivity can be effectively increased.
(55) Moreover, according to the embodiments of this disclosure, the sensors of the tool holder having force sensors are arranged symmetrically with respect to a point. The point symmetrical arrangement of force sensors enable the force sensors to effectively sense the multi-axial forces applied to the entire tool holder, such that the sensing performance of the sensors is improved.
(56) Furthermore, according to the embodiments of this disclosure, the sensors of the tool holder having force sensors not only can directly display the measured torsional force and measured bending force on the displayer device, but also can transmit the measured data in real time through a wireless communication to the data management platform in the mobile device such as a tablet computer, a mobile phone or a notebook computer.
(57) It can be seen that this disclosure has indeed achieved the effect of desired improvement under the breakthrough of the existing technology, and it is not obvious for those who are familiar with this skill to think about it. Its progressiveness and practicality have obviously met the requirements of the patent.
(58) It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed embodiments without departing from the scope or spirit of the disclosure. It is intended that the specification and examples be considered as exemplars only, with a true scope of the disclosure being indicated by the following claims and their equivalents.

Claims

1. A tool holder having force sensors, comprising: a first connection portion connecting a cutting tool along an axis; a second connection portion being connected to a spindle along the axis; a first sensing portion having at least one first hole and connecting the first connection portion along the axis; a second sensing portion having at least one second hole and connecting the second connection portion and the first sensing portion along the axis; at least one first force sensor disposed in the at least one first hole and configured to sense a torsional force; and at least one second force sensor disposed in the at least one second hole and configured to sense a bending force; wherein a second bending stiffness of the second sensing portion is less than a first bending stiffness of the first sensing portion.
2. The tool holder having force sensors of claim 1, wherein a first torsional stiffness of the first sensing portion is less than a second torsional stiffness of the second sensing portion.
3. The tool holder having force sensors of claim 2, wherein the first sensing portion includes two first holes of the at least one first hole, the second sensing portion includes two second holes of the at least one second hole, a first line passes through the at least one first hole and the axis, and a second line passes through the at least one second hole and the axis.
4. The tool holder having force sensors of claim 3, wherein the second sensing portion further includes another two second holes of the at least one second hole, a third line passes through said another two second holes and the axis, and the second line and the third line are perpendicular to each other.
5. The tool holder having force sensors of claim 3, wherein the first sensing portion further includes a cross section, a normal vector is parallel to the axis, a projection angle is formed between a first projection of the first line on the cross section and a second projection of the second line on the cross section.
6. The tool holder having force sensors of claim 5, wherein the projection angle is substantially equal to −45° or +45°.
7. The tool holder having force sensors of claim 5, wherein the projection angle is substantially

equal to −135° or +135°.
8. The tool holder having force sensors of claim 5, wherein the first force sensor includes a first sensing element having a first sensing surface, a first sensing angle is formed between a first normal vector of the first sensing surface and the axis, the second force sensor includes a second sensing element having a second sensing surface, a second sensing angle is formed between a second normal vector of the second sensing surface and the axis, the first sensing angle is substantially not equal to the second sensing angle.
9. The tool holder having force sensors of claim 8, wherein when the first force sensor is disposed in the at least one first hole, the first sensing angle is adjustable; and when the second force sensor is disposed in the at least one second hole, the second sensing angle is adjustable.
10. The tool holder having force sensors of claim 8, wherein the first sensing angle is substantially equal to −45° or +45°.
11. The tool holder having force sensors of claim 8, wherein the second sensing angle is substantially equal to 0° or 180°.
12. A tool holder having force sensors, comprising: a first connection portion connecting a cutting tool along an axis; a second connection portion being connected to a spindle along the axis; a first sensing portion having at least one first hole and connecting the first connection portion along the axis; a second sensing portion having at least one second hole and connecting the second connection portion and the first sensing portion along the axis; at least one first force sensor disposed in the at least one first hole and configured to sense a torsional force; and at least one second force sensor disposed in the at least one second hole and configured to sense a bending force; wherein a first torsional stiffness of the first sensing portion is less than a second torsional stiffness of the second sensing portion.
13. The tool holder having force sensors of claim 12, wherein the first force sensor includes a first sensing element having a first sensing surface, a first sensing angle is formed between a first normal vector of the first sensing surface and the axis, the second force sensor includes a second sensing element having a second sensing surface, a second sensing angle is formed between a second normal vector of the second sensing surface and the axis, the first sensing angle is substantially not equal to the second sensing angle.
14. The tool holder having force sensors of claim 13, wherein when the first force sensor is disposed in the at least one first hole and the first sensing angle is adjustable; and when the second force sensor is disposed in the at least one second hole and the second sensing angle is adjustable.
15. The tool holder having force sensors of claim 13, wherein the first sensing angle is substantially equal to −45° or +45°.
16. The tool holder having force sensors of claim 13, wherein the second sensing angle is substantially equal to 0° or 180°.