(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 249 350 B1

(12) # EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
27.11.2019 Bulletin 2019/48

(21) Application number: **15808066.3**

(22) Date of filing: **22.01.2015**

(51) Int Cl.:
G01B 11/26 (2006.01) ***G01B 11/02*** (2006.01)
B23Q 17/24 (2006.01) ***G01B 21/04*** (2006.01)
G01B 11/27 (2006.01) ***G01B 11/00*** (2006.01)

(86) International application number:
PCT/CN2015/071300

(87) International publication number:
WO 2016/115704 (28.07.2016 Gazette 2016/30)

(54) **LASER MEASUREMENT SYSTEM CAPABLE OF DETECTING 21 GEOMETRIC ERRORS**

LASERMESSSYSTEM ZUM NACHWEIS VON 21 GEOMETRIEFEHLERN

SYSTÈME DE MESURE PAR LASER POUR DÉTECTER 21 ERREURS GÉOMÉTRIQUES

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR

(43) Date of publication of application:
29.11.2017 Bulletin 2017/48

(73) Proprietor: **Beijing Jiaotong University**
Beijing 100044 (CN)

(72) Inventors:
- **FENG, Qibo**
  Beijing 100044 (CN)
- **ZHANG, Bin**
  Beijing 100044 (CN)
- **CUI, Cunxing**
  Beijing 100044 (CN)

(74) Representative: **Mittler, Enrico et al**
Mittler & C. S.r.l.
Viale Lombardia, 20
20131 Milano (IT)

(56) References cited:
EP-A1- 2 219 010 **EP-A1- 3 190 381**
CA-A1- 2 270 228 **CN-A- 1 205 077**
CN-A- 103 424 069 **CN-A- 103 673 891**
CN-A- 103 940 348 **CN-Y- 2 884 141**
US-A- 4 939 678 **US-A- 5 798 828**
US-A1- 2005 024 649

- **DATABASE WPI Week 201032 Thomson Scientific, London, GB; AN 2010-E99783 XP002781211, -& CN 2 884 141 Y (UNIV BEIJING JIAOTONG) 28 March 2007 (2007-03-28)**

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

EP 3 249 350 B1

Description

FIELD OF THE INVENTION

[0001] The present invention relates to a laser measurement system and method for measuring up to 21 GMEs (geometric motion errors), which is used to an accuracy measurement for precise machining and measuring equipment, such as a numerical control machine tool, a machining center or a coordinate measuring machine. The field of the invention pertains to the dimensional geometric accuracy measurement, particularly to a laser measurement system and method for measuring the 21 GMEs of three mutual perpendicular linear motion guides of the equipment listed above by a single installation and step-by-step measurement.

[0002] The 21 GMEs include the 6GMEs of the X-axis, the 6GMEs of the Y-axis, the 6GMEs of the Z-axis, the perpendicularity error between the X-axis and the Y-axis, the perpendicularity error between the Y-axis and the Z-axis, and the perpendicularity error between the X-axis and the Z-axis.

BACKGROUND OF THE INVENTION

[0003] DE10341594A1 discloses a method for directly measuring the geometric errors of the numerical control machine tool, the machining center or the coordinate measuring machine. The beam from the laser interferometer is splitted to be parallel to the three linear motion axes of the equipment listed above. The laser interferometer directly measures the geometric errors of the three linear motion axes. However, the system configuration is complicated, and the assembly and adjustment of the system is difficult. Moreover, the roll error of the three linear motion axes cannot be measured.

[0004] In prior art, there exist no such a measurement system which offers simple configuration and convenient operation, and can directly measure up to 21 GMEs of three mutual perpendicular linear motion axes by a single installation and step-by-step measurement.

[0005] CN2884141Y discloses a prior art laser 6 DOF simultaneous measure device, which is performed by a polarization spectrum machine 2, quarter wave pieces 17 and 19, and semitransparent half reflection mirrors 4, 6, 18, etc. That is, CN2884141Y works in a way of polarization spectrum.

[0006] US4,939,678 discloses a method for calibration of coordinate measuring machine, in which the axial errors are subtracted from the scale readings.

[0007] In prior art, dually collimated beams have never been used to used to measure geometric motion errors (GMEs).

SUMMARY OF THE INVENTION

[0008] The object of the present invention is to provide a laser measurement system for measuring up to 21 GMEs of three mutual perpendicular linear motion guides of precise machining and measuring equipment, such as a numerical control machine tool, a machining center or a coordinate measuring machine, which is of simple configuration and allows for convenient operation. The 21 GMEs of three mutual perpendicular linear motion guides are directly measured by a single installation and step-by-step measurement.

[0009] Thus, according to one aspect of the present invention, there provides a laser measurement system for measuring up to 21 GMEs as defined in claim 1.

[0010] The laser measuring system comprises a 6DOF (six-degree-of-freedom) GME simultaneous measurement unit, a beam-turning unit, and an error-sensitive unit. The 6DOF GME simultaneous measurement unit is combined with the error-sensitive unit to simultaneously measure the 6DOF GME of a single axis, which includes position error, horizontal and vertical straightness errors, yaw, pitch, and roll. There are 18 GMEs for the three axes. The beam-turning unit splits or turns the laser beam from the 6DOF GME simultaneous measurement unit to the X, Y and Z directions in proper order. Similarly, the beam-turning unit splits or turns the beam from the error-sensitive unit to the 6DOF GME simultaneous measurement unit to simultaneously measure the 6DOF GMEs of the corresponding axis. The perpendicularity errors among the three axes are obtained by processing the straightness errors of the three axes.

[0011] Preferably, the error-sensitive unit is composed of three mutual perpendicular 6DOF error-sensitive components, which are sensitive to the 6DOF GMEs of three mutual perpendicular linear motion axes of the equipment listed above. Similarly, the error-sensitive unit is composed of two mutually perpendicular 6DOF error-sensitive components, which are sensitive to the 6DOF GMEs of two mutually perpendicular linear motion axes of the equipment listed above. One of the two 6DOF error-sensitive components is sensitive to the 6DOF GME of the third linear motion axis of the equipment listed above through a 90-degree rotation.

[0012] The 6DOF error-sensitive component consists of two retro-reflector elements and one beam-splitting element. The retro-reflector element is sensitive to the position error, horizontal straightness error, and vertical straightness error of a linear motion axis. The beam-splitting element is sensitive to the pitch and yaw of the linear motion axis. The combination of the two retro-reflector elements is sensitive to the roll of the linear motion axis. The cube-corner reflector is used as the retro-reflector element, and the plane beam-splitter is used as the beam-splitting element.

[0013] Preferably, the beam-turning unit consists of the beam-turning prism, or the combination of the beam-splitting prism and the beam-turning prism. Through translation and rotation, the beam-turning prism, which includes a polygon prism or a rectangle prism, turns the measurement beam from the 6DOF GME simultaneous measurement unit to the directions which are parallel to the three linear motion axes of the equipment listed above. The combination of the beam-splitting prism and the beam-turning prism is the combination of two beam-splitting polygon prisms, or the combination of two beam-splitting rectangle prisms. The beam from the 6DOF GME error simultaneous measurement unit is split into three mutual perpendicular beams, which are parallel to the three linear motion axes of the equipment listed above.

[0014] According to another not-claimed aspect of the present invention, there provides a method for measuring up to 21 geometric errors of the precise machining and measuring equipment, such as a numerical control machine tool, a machining center, and a coordinate measuring machine by single installation and step-by-step measurement. This method includes the following procedures:

(1) installing the measurement system. The 6DOF GME simultaneous measurement unit and the beam-turning unit are mounted independently or integrally on the clamping workpiece of the equipment listed above. The error-sensitive unit is mounted on the clamping tool of the equipment listed above.

(2) adjusting the measurement system. The three axes of the equipment listed above are adjusted to the initial positions predetermined by measurement standards such as ISO 230-1. The error-sensitive unit is placed as close as possible to the beam-turning unit, and this predetermined initial position is defined as the start point. By adjusting the 6DOF GME simultaneous measurement unit and the beam-turning unit, the three measurement beams, which are parallel to the X, Y, and Z axes of the equipment listed above, are obtained simultaneously or in separate steps according to the different beam turning structures of the laser beam-turning unit.

(3) measuring the 6DOF GMEs of the X-axis. The beam-turning unit directs the beam from the six-degree-of-freedom geometric error simultaneous measurement unit to the direction parallel to the X-axis of the equipment listed above. Controlling the motion of the equipment listed above, the laser measurement system for 21 geometric errors is set to the start point. The 6DOF GMEs of the start point, including position error, horizontal and vertical straightness errors, pitch, yaw, and roll, are obtained by the 6DOF GME simultaneous measurement unit combined with the corresponding 6DOF error-sensitive component of the error-sensitive unit. The linear guide moves along the X-axis with the interval predetermined by related measurement standards, such as ISO230-1, and reaches the next measurement point while the Y and Z axes are kept static. The 6DOF GMEs of this point are measured. The measurement is performed point-by-point until the last measurement point, and the errors of all the measurement points on the X-axis are obtained. The linear guide moves along the X-axis in the opposite direction with the same interval. The measurement is performed point-by-point to obtain the errors of all the measurement points. In this way, the errors of all the measurement points in bidirectional movement are obtained through point-by-point static measurement. In another way, the linear guide moves from the start point to the farthest end and returns to the start point in a constant speed, and the continuous measurement is conducted by the 6DOF GME simultaneous measurement unit, combined with the corresponding 6DOF error-sensitive component of the error-sensitive unit. The errors of all the measurement points on the X-axis in bidirectional movement are obtained through dynamic measurement.

(4) measuring the 6DOG GMEs of the Y-axis. The beam-turning unit directs the beam from the 6DOF GME simultaneous measurement unit to the direction parallel to the Y-axis of the equipment previously listed. The linear guide moves along the Y-axis according to the procedures mentioned in step (3), and the errors of all the measurement points on the Y-axis in bidirectional movement are obtained through point-by-point static measurement or continuous dynamic measurement.

(5) measuring the 6Ddof GMEs of the Z-axis. The beam-turning unit directs the beam from the 6DOF geometric error simultaneous measurement unit to the direction parallel to the Z-axis of the equipment previously listed. The linear guide moves along the Z-axis according to the procedures mentioned in step (3), and the errors of all the measurement points on the Z-axis in bidirectional movement are obtained through point-by-point static measurement or continuous dynamic measurement.

(6) Data processing. By performing steps (3), (4), and (5), the invention obtains 6DOF GMEs of each of the measurement points on the X, Y and Z axes of the measured equipment previously listed in bidirectional movement. The total errors are 18. The three perpendicularity errors among the three motion axes are obtained by data processing according to the measurement standards, such as ISO 230-1. Therefore, a total of 21 geometric errors are obtained.

[0015] The order of measuring the X, Y and Z axes according to steps (3), (4), and (5) has no influence on the measurement results. The same results are obtained by performing steps (1) through (6) when the error-sensitive unit is fixed on the clamping workpiece and the 6DOF GMEs simultaneous measurement unit and the beam-turning unit are mounted integrally on the clamping tool of the equipment previously listed.

[0016] The advantages of the present invention are as follows:

(1) The 6DOF error-sensitive component in the

present invention consists of two retro-reflector elements and one beam-splitting element. Only two measurement beams need to simultaneously measure the 6DOF GMEs for one axis. There are fewer beam-splitting elements in the system, which makes the system highly integrated.

(2) Only a single installation is needed to calibrate the three linear motion axes of the equipment previously listed. The measurement efficiency is highly improved.

(3) Three mutual perpendicular measurement beams, which are used as the reference datum for the perpendicularity error measurement, are obtained through the beam-turning unit. The three perpendicularity errors are obtained by processing data of the geometric errors of the three linear motion axes.

[0017] Generally speaking, the invention is of simple configuration and allows for high integration with fewer optical elements. The 21 GMEs of three linear motion guides of the equipment previously listed are obtained through single installation and step-by-step measurement.

[0018] A reliable instrument that simultaneously measures the 6DOF GMEs is not available in prior art. The present invention measures not only the 6DOF GMEs of a single axis, but also the 21 GMEs of three axes. The measurement system provided by the invention is of small size, and allows high integration and accuracy. The system is strongly immune from surrounding disturbance because the laser drift can be compensated in real time.

[0019] In conventional measurement methods, three mutual perpendicular datum lines are obtained by mechanical components or optical elements, and several manual installations are needed. Therefore, installation deviation is introduced during the installation process. The beam-turning unit consists of the beam-turning prism or the combination of the beam-splitting prism and the beam-turning prism. The three measurement beams, which are parallel to the three linear motion axes and are used as the measurement reference datum lines for three perpendicularity errors, are obtained simultaneously or step-by-step by the beam-turning unit based on the inherent properties of optical elements and the precision electro-kinetic rotation axis for 90-degree rotation.

[0020] In conventional measurement methods for multi-axes, different installations are needed to realign the measurement unit and the moving unit during the measurement of different axes. The measured parameters are limited, and the measurement efficiency is low. The proposed measurement system contains the beam-turning unit and the error-sensitive unit, which is composed of three mutual perpendicular 6DOF error-sensitive components. Three mutual perpendicular measurement beams are obtained by adjusting the positions and directions of the 6DOF GME simultaneous measurement unit and the beam-turning unit after the system installation and before the actual measurement. The alignment of the three measurement beams and the three 6DOF error-sensitive components is achieved by the movement of linear guide along the three axes. The 21 GMEs are measured through single installation and step-by-step measurement, which greatly improves the measurement efficiency and reduces the potential for manual errors.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021]

Fig. 1 is a schematic view of the first embodiment of the laser measurement system for 21 GMEs provided by the present invention.

Fig. 2 is a schematic view of the second embodiment of the laser measurement system for 21 GMEs provided by the present invention.

Fig. 3 is a schematic view of the first type of beam-turning unit in the present invention.

Fig. 4 is a schematic view of the second type of beam-turning unit in the present invention.

Fig. 5 is a schematic view of the third type of beam-turning unit in the present invention.

Fig. 6 is a schematic view of the fourth type of beam-turning unit in the present invention.

Fig. 7 is a schematic view of the first type of error-sensitive unit in the present invention.

Fig. 8 is the schematic view of the second type of error-sensitive unit in the present invention.

Fig. 9 is a schematic view of the third type of error-sensitive unit in the present invention.

Fig. 10 is a schematic view of the fourth type of error-sensitive unit in the present invention.

Fig. 11 is a schematic view of the fifth type of error-sensitive unit in the present invention.

Fig. 12 is a schematic view of simultaneous measurement for the 6DOF GMEs along the X-axis in the present invention.

Fig. 13 is a schematic view of simultaneous measurement for the 6DOF GMEs along the Y-axis in the present invention.

Fig. 14 is a schematic view of the start point for measuring 21 GMEs provided by the present invention.

Fig. 15 is a schematic view of the measurement along the X-axis in the laser measurement method for 21 GMEs provided by the present invention.

Fig. 16 is a schematic view of the measurement along the Y-axis in the laser measurement method for 21 GMEs provided by the present invention.

Fig. 17 is a schematic view of the measurement along the Z-axis in the laser measurement method for 21 GMEs provided by the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] As shown in Fig. 1, the laser measurement system for the 21 GMEs provided by the present invention consists of the 6DOF GME simultaneous measurement unit 1, the beam-turning unit 2 and the error-sensitive unit 3. The error-sensitive unit 3 is fixed on the clamping tool of the measured numerical control machine tool, the machining center, and the coordinate measuring machine. The measurement unit 1 and the beam-turning unit 2 are mounted on the clamping workpiece of the equipment previously listed.

[0023] Referring to Fig. 2, the error-sensitive unit 3 can also be fixed on the clamping workpiece, while the measurement unit 1 and the beam-turning unit 2 can also be mounted on the clamping tool of the equipment previously listed.

[0024] As shown in Fig. 3, the pentagonal prism 2011 is used in the beam turning 2 to turn the laser beam from the measurement unit 1. The pentagonal prism 2011 is removed from the light path of measurement unit 1 by manual or electro-kinetic operation. The measurement beam, which is parallel to the X-axis and reaches the 6DOF error-sensitive component 301, is obtained by adjusting the position and direction of the measurement unit 1. The pentagonal prism 2011 is then placed into the light path of the measurement unit 1 by manual or electro-kinetic operation. The measurement beam, which is parallel to the Y-axis and reaches the six-degree-of-freedom error-sensitive component 302, is obtained by adjusting the pentagonal prism 2011 to make the measurement beam enter it perpendicularly. The straight line parallel to X-axis and passing through the center of the incident plane of the pentagonal prism 2011 is used as the rotation axis. The pentagonal prism 2011 is rotated by 90 degrees through the precise rotation component which is fixed with the pentagonal prism 2011. The measurement beam, which is parallel to the Z-axis and reaches the 6DOF error-sensitive component 303, is then obtained. In this way, the three measurement beams, which are parallel to the X, Y, and Z axes of the previously listed equipment are obtained step-by-step by the first type of the beam-turning unit 2.

[0025] Referring to Fig. 4, the second type of beam-turning unit 2 is composed of the beam splitting pentagonal prisms 2021 and 2022. The measurement beam, which is parallel to the X-axis, is obtained by adjusting the position and direction of the measurement unit 1. The combination of the beam splitting pentagonal prisms 2021 and 2022 is then placed into the light path of the measurement unit 1. The beam from measurement unit 1 perpendicularly enters onto the beam splitting pentagonal prism 2021, and the reflected beam from the beam splitting pentagonal prism 2021 perpendicularly enters the beam splitting pentagonal prism 2022 by adjusting the position of the beam splitting pentagonal prisms 2021 and 2022. The three measurement beams, which are parallel to the X, Y, and Z axes of the measured equipment listed above, are obtained simultaneously by the second type of beam-turning unit 2.

[0026] As shown in Fig. 5, the rectangle prism 2031 is used in the beam-turning unit 2 to turn the laser beam from the measurement unit 1. The rectangle prism 2031 is removed from the light path of the measurement unit 1 through manual or electro-kinetic operation. The measurement beam, which is parallel to the X-axis and reaches the six-degree-of-freedom error-sensitive component 301, is obtained by adjusting the position and direction of the measurement unit 1. The rectangle prism 2031 is then placed into the light path of the measurement unit 1 through manual or electro-kinetic operation. By adjusting the rectangle prism 2031 to make the measurement beam enters it perpendicularly, the measurement beam, which is parallel to the Y-axis and reaches the six-degree-of-freedom error-sensitive component 302, is obtained. The straight line parallel to the X-axis and passing through the center of the incident plane of the pentagonal prism 2031 is used as the rotation axis. The pentagonal prism 2031 is rotated by 90 degrees through the precise rotation component which is fixed with the pentagonal prism 2031. The measurement beam, which is parallel to the Z-axis and reaches the six-degree-of-freedom error-sensitive component 303, is then obtained. In this way, the three measurement beams, which are parallel to the X, Y, and Z axes of the measured equipment previously listed, are obtained step-by-step by the second type of the beam-turning unit 2.

[0027] Referring to Fig. 6, the fourth type of beam-turning unit 2 is composed of the beam splitting prisms 2041 and 2042. The measurement beam, which is parallel to the X-axis, is obtained by adjusting the position and direction of the measurement unit 1. The combination of the beam splitting prisms 2041 and 2042 is then placed into the light path of the measurement unit 1. The beam from the measurement unit 1 perpendicularly enters the beam splitting prism 2041, and the reflected beam from the beam splitting prism 2041 is directed to perpendicularly enter the beam splitting prism 2042 through adjustment of the position of the beam splitting prisms 2041 and 2042. The three measurement beams, which are parallel to the X, Y, and Z axes of the measured equipment list above, are obtained simultaneously by the fourth type of the beam-turning unit 2.

[0028] As shown in Fig. 3 through Fig. 6, the three mutually perpendicular measurement beams, which are parallel to the X, Y, and Z axes of the equipment previously listed, are obtained simultaneously or step-by-step by four different types of the beam-turning unit 2. The optical property of the beam turning prism and the combination of the beam splitting and turning prisms will result in a difference in the relative order of the two measurement beams, which are from the measurement unit 1 and are turned by the beam-turning unit 2 to the direction perpendicular to the beam transmission direction. Therefore, different types of the error-sensitive unit 3 are needed to cooperate with the different types of beam-turning unit 2.

[0029] The first type of the error-sensitive unit 3, which is corresponding to the first type of the beam-turning unit

2, is shown in Fig. 7. The error-sensitive unit 3 consists of three mutual perpendicular 6DOF error-sensitive components 301, 302 and 303, which are sensitive to the six degree-of-freedom geometric errors of the X, Y, and Z axes of the equipment previously listed.

[0030] The 6DOF error sensitive component 301 consists of two retro-reflector elements 3011 and 3012, and one beam-splitting element 3013. The retro-reflector element 3011 is sensitive to the position error, horizontal straightness error, and vertical straightness error of the X-axis. The beam-splitting element 3013 is sensitive to the pitch and yaw of the X-axis. The combination of the two retro-reflector elements 3011 and 3012 is sensitive to the roll of the X-axis.

[0031] The 6DOF error sensitive component 302 consists of two retro-reflector elements 3021 and 3022, and one beam-splitting element 3023. The retro-reflector element 3021 is sensitive to the positioning error, horizontal and vertical straightness error of the Y-axis. The beam-splitting element 3023 is sensitive to the pitch and yaw of the Y-axis. The combination of the two retro-reflector elements 3021 and 3022 is sensitive to the roll of the Y-axis.

[0032] The 6DOF error sensitive component 303 consists of two retro-reflector elements 3031 and 3032, and one beam-splitting element 3033. The retro-reflector element 3031 is sensitive to the positioning error, horizontal and vertical straightness error of the Z-axis. The beam-splitting element 3033 is sensitive to the pitch and yaw of the Z-axis. The combination of the two retro-reflector elements 3031 and 3032 is sensitive to the roll of the Z-axis.

[0033] The second, third and fourth types of the error sensitive unit 3, which correspond to the second, third and fourth types of the beam-turning unit 2, respectively, are shown in Fig. 8, Fig. 9 and Fig. 10. Each type of the error sensitive unit 3 is composed of three mutual perpendicular 6DOF error sensitive components 301, 302, and 303, which are sensitive to the 6DOF GMEs of the X, Y, and Z axes of the measured equipment previously listed. The positions of the retro-reflector elements and the beam-splitting elements in 6DOF error sensitive components 301, 302, and 303 correspond to the positions of the two measurement beams, from the measurement unit 1 to the 6DOF error sensitive components 301, 302, and 303, after the transmission from the beam turning unit 2.

[0034] As shown in Fig. 11, the fifth type of the error sensitive unit 3 consists of two mutually perpendicular 6DOF error-sensitive components 301 and 302, which are sensitive to the 6DOF GMEs of the X and Z axes of the equipment to be measured previously listed. The 6DOF error sensitive component 301 is sensitive to the 6DOF GMEs of the Y-axis after 90-degree rotation around the Z axis.

[0035] The cube-corner reflectors are used as the retro-reflector elements 3011, 3012, 3021, 3022, 3031, and 3032, shown in Fig. 7 through Fig. 11. The plane beam-splitter or the beam-splitting film which is coated on the corresponding position of the retro-reflector element is used as the beam-splitting elements 3013, 3023, and 3033.

[0036] As shown in Fig. 3, the pentagonal prism 2011 is used in the first type of the beam-turning unit 2 to obtain step-by-step the measurement beams, which are parallel to the X, Y, and Z axes of the equipment previously listed. The pentagonal prism 2011 has no influence on the relative order of the two measurement beams emitted from the measurement unit 1 in the transmission directions. It also does not change the relative positions between the reference datum line for angle measurement and the angle measurement beams, which are reflected by the beam-splitting elements 3013, 3023, and 3033. Therefore, the first type of beam-turning unit 2 is used in the preferred embodiment of the present invention to simultaneously measure the 6DOF GMEs of each linear motion axis.

[0037] As shown in Fig. 12, the 6DOF GMEs of the X-axis of the equipment to be measured previously listed are simultaneously measured by the measurement unit 1 in cooperation with the 6DOF error-sensitive component 301. The measurement unit 1 consists of the dual frequency laser 101; the quarter-wave plates 102 and 107; the polarization beam-splitters 103 and 106; the beam-splitters 104, 108, and 109; the retro-reflector element 105; the beam-reflecting elements 110 and 114; the detectors 111, 112, 113, 116 and 118; the lens 115 and 117. The six-degree-of-freedom error-sensitive component 301 consists of the retro-reflector elements 3011 and 3012, and the beam-splitting element 3013.

[0038] As shown in Fig. 12, the error-sensitive unit 3 and the 6DOF error-sensitive component 301 move along the X-axis to a certain measurement point. During the measurement process of the X-axis, the pentagonal prism 2011 in the beam-turning unit 2 is moved out of the light path of the measurement unit 1.

[0039] The beam from the dual frequency laser 101 passes through the quarter-wave plate 102 and is split by the polarization beam-splitter 103. The reflected beam from 103 is split again by the beam-splitter 104, and the transmitted beam from 104 is used as the reference beam for interferometric length measurement. The transmitted beam from the polarization beam-splitter 103 is reflected by the retro-reflector element 3011 and split by the beam-splitter 108. The transmitted beam from beam-splitter 108 and the reflected beam from the retro-reflector element 105 interfere on the detector 111, and the position error of the measurement point on the X-axis is obtained.

[0040] The reflected beam from the beam-splitter 108 is split by the beam-splitter 109. The reflected beam from the beam-splitter 109 reaches the detector 112. The horizontal and vertical straightness errors of the measurement point on the X-axis are obtained.

[0041] The transmitted beam from the beam-splitter 109 is reflected by the beam-reflecting element 110 and is focused onto the detector 118 by lens 117. The angular drift of the measurement beam is measured in this way.

[0042] The reflected beam from the beam-splitter 104 passes through the polarization beam-splitter 106 and the quarter-wave plate 107, and is partially reflected by the beam-splitting element 3013. The reflected beam from 3013 passes through the quarter-wave plate 107, and is totally reflected by the polarization beam-splitter 106. The reflected beam from the beam-splitter 106 is reflected by the beam-reflecting element 114 and is focused onto the detector 116 by lens 115. The pitch and yaw of the measurement point on the X-axis are obtained.

[0043] The transmitted beam from the beam-splitting element 3013 is reflected by the retro-reflector element 3012 and is directed onto the detector 113. The horizontal and vertical straightness errors of the measurement point on the X-axis are obtained.

[0044] The vertical straightness errors of two different measurement points on the X-axis with the same horizontal position are measured by the detectors 112 and 113. The roll of the measurement point on the X-axis is calculated using these two straightness errors.

[0045] As shown in Fig. 13, the 6DOF GMEs of the Y and Z axes of the measured equipment previously listed are simultaneously measured by the measurement unit 1 in cooperation with the beam-turning unit 2 and the error-sensitive unit 3.

[0046] The error-sensitive unit 3 and the 6DOF error-sensitive component 302 move along the Y-axis to a certain measurement point. The transmitted beam from the polarization beam-splitter 103 and the reflected beam from the beam-splitter 104, which are parallel to the X-axis, are used as the measurement beams. The measurement beams are turned in the directions parallel to the Y-axis by the pentagonal prism 2011 in the beam-turning unit 2 and reach the 6DOF error-sensitive component 302. The reflected beam from the beam-splitting element 3023 and the reflected beam from the retro-reflector elements 3021 and 3022 are then turned back to the measurement unit 1 by the beam-turning unit 2. The 6DOF GMEs of the Y-axis are measured in this way.

[0047] Similarly, the beam from the measurement unit 1 is turned in the direction parallel to the Z-axis by the beam-turning unit 2. The 6DOF GMEs of the Z-axis are obtained by the measurement unit 1 in cooperation with the beam-turning unit 2 and the 6DOF error-sensitive component 303.

[0048] A method for measuring 21 GMEs through single installation and step-by-step measurement is provided and used in the present system. The 21 GMEs of the numerical control machine tool, the machining center, or the coordinate measuring machine are obtained according to the following procedures:

1) installing the measurement system. As shown in Fig. 1, the 6DOF GME simultaneous measurement unit 1 and the beam-turning unit 2 are mounted on the clamping workpiece of the equipment to be measured listed above. The error-sensitive unit 3 is fixed on the clamping tool.

2) adjusting the measurement system. As shown in Fig. 14, the three axes of the precise machining and measuring equipment listed above are adjusted to the initial position predetermined by related measurement standards, such as ISO 230-1, and the error-sensitive unit 3 is placed as close as possible to the beam-turning unit 2. This predetermined initial position is defined as the start point. The positions and directions of the measurement unit 1 and the beam-turning unit 2 are adjusted simultaneously or in separate steps to obtain the three measurement beams, which are parallel to the X, Y, and Z axes of the equipment listed above, according to the different laser turning structures of the beam-turning unit 2. The three measurement beams are mutually perpendicular, according to the inherent property of the beam-turning unit 2, and are used as the reference datum lines for perpendicularity error measurement.

3) measuring the 6DOF GMEs of the X-axis. As shown in Fig. 15, the beam from the measurement unit 1 is directed to be parallel to the X-axis of the equipment by the beam-turning unit 2. By controlling the motion of the equipment, the laser measurement system for 21 GMEs is set at the start point. The 6DOF GMEs of the start point of the X-axis, including the position error, the horizontal and vertical straightness errors, and pitch, yaw, and roll, are obtained by the measurement unit 1 combined with the corresponding six-degree-of-freedom error-sensitive component 301 on the error-sensitive unit 3. The linear guide moves along the X-axis with the interval predetermined by related measurement standards, such as ISO 230-1, and reaches the next measurement point while the Y and Z axes are kept static. The six degree-of-freedom geometric errors of this point are measured by the measurement unit 1. The measurement of the X-axis is performed point-by-point to the last measurement point and the six degree-of-freedom geometric errors of each of the measurement points on the X-axis are obtained. The linear guide moves along the X-axis in the opposite direction with the same interval, and the measurement is performed point-by-point to obtain the errors of all of the measurement points. In this way, the 6DOF GMEs of each of the measurement points in bidirectional movement are obtained through point-to-point static measurement. The errors of all the measurement points in bidirectional movement are obtained more than once by repeating the mentioned procedures. In another usage option, the linear guide moves from the start point to the farthest end and returns to the start point in constant speed, and continuous measurements are obtained by the measurement unit 1, combined with the corresponding 6DOF error-sensitive component on the error-sensitive unit 3. The errors of all the measurement points on the X-axis in bidirectional movement are obtained

through dynamic measurement.

4) measuring the 6DOF GMEs of the Y-axis. As shown in Fig. 16, the beam-turning unit 2 points the beam from the measurement unit 1 in the direction parallel to the Y-axis of the equipment previously listed. The Y-axis linear guide moves according to the procedures mentioned in step 3), and the 6DOF GMEs of each of the measurement points on the Y-axis in bidirectional movement are obtained through point-by-point static measurement or continuous dynamic measurement.

5) measuring the 6DOF GMEs of Z-axis. As shown in Fig. 17, the beam-turning unit 2 points the beam from the measurement unit 1 in the direction parallel to the Z-axis of the equipment previously listed. The Z-axis linear guide moves according to the procedures mentioned in steps 3) or 4), and the 6DOF GMEs of each of the measurement points on the Z-axis in bidirectional movement are obtained through point-by-point static measurement or continuous dynamic measurement.

6) Data processing. The 18 geometric errors are obtained through point-by-point static measurement or continuous dynamic measurement by performing steps (3), (4) and (5). The angle between the motion trajectory along the three axes and the measurement beam for corresponding axes, which is the reference datum for perpendicularity error measurement, can be calculated by processing the straightness errors of the three axes. The perpendicularity errors among the three motion axes can then be obtained. Therefore, a total of 21 GMEs are obtained.

Claims

1. A laser measurement system for measuring up to 21 geometric motion errors, GME, of a precise machining and measuring equipment, comprising a 6 degrees of freedom, DOF, GME simultaneous measurement unit (1) with two measurement beams, a beam-turning unit (2), and an error-sensitive unit (3), wherein

the 6DOF GME simultaneous measurement unit (1) and the beam-turning unit (2) are mountable on a clamping workpiece, while the error-sensitive unit (3) is mountable on a clamping tool;

the 6DOF GME simultaneous measurement unit (1) is adapted to cooperate with the error-sensitive unit (3) to simultaneously or individually measure the GMEs of 6DOF of a single axis of the precise machining and measuring equipment; the 6DOF GME simultaneous measurement unit (1) comprises a dual frequency laser (101) for providing a single dual frequency laser beam, quarter-wave plates (102, 107), polarization beam-splitters (103, 106) for dividing the single beam into two measurement beams, beam-splitters (104, 108, 109), a retro-reflector element (105), beam-reflecting elements (110, 114), detectors (111, 112, 113, 116, 118) and lenses (115, 117); the beam-turning unit (2) is adapted to split or turn the measurement beams from the 6DOF GME measurement unit (1) to the X, Y and Z directions in proper order, and is adapted to split or turn the reflected measurement beams from the error-sensitive unit (3, 301, 302) to the 6DOF GME measurement unit (1), so as to be adapted to simultaneously measure the 6DOF geometric errors of each corresponding axis;

the 6DOF error-sensitive unit (3) comprises two retro-reflector elements (3011, 3012; 3021, 3022) and one beam-splitting element (3013, 3023); the retroreflector elements (3011, 3012; 3021, 3022) being sensitive to the position error, the horizontal straightness error, and the vertical straightness error of a linear motion axis; the beam-splitting element (3013, 3023) being sensitive to the pitch and the yaw of the linear motion axis; a combination of the two retroreflector elements (3011, 3012; 3021, 3022) being sensitive to the roll of the linear motion axis; a cube-corner reflector is adapted to be used for each retroreflector element, and a plane beam-splitter is adapted to be used as the beam-splitting element; and

the perpendicularity errors among the three axes are calculatable from the straightness errors of the three axes.

2. The system according to claim 1, wherein the error-sensitive unit (3) comprises three mutually perpendicular 6DOF error-sensitive components (301, 302, 303), which are sensitive to the 6DOF GMEs of the three mutually perpendicular linear motion axes (X, Y, Z) of the equipment, respectively.

3. The system according to claim 1, wherein the beam-turning unit (2) comprises a beam-turning prism (2011), or a combination of a beam-splitting prism (2021, 2022) and a beam-turning prism; through translation and rotation, the beam-turning prism, which includes a polygon prism or a rectangle prism, is adapted to turn the measurement beam from the 6DOF GME measurement unit (1) to the directions which are parallel to the three linear motion axes of the equipment in separate steps; the combination of the beam-splitting prism and the beam-turning prism is a combination of two beam-splitting polygon prisms, or a combination of two beam-splitting rectangle prisms, the beam from the 6DOF GME measurement unit (1) is adapted to simultaneously split into three mutually perpendicular beams, which are parallel to the three linear motion axes of the equipment.

Patentansprüche

1. Lasermesssystem zum Messen von bis zu 21 geometrischen Bewegungsfehlern, GME (geometric motion errors), einer präzisen Bearbeitungs- und Messausrüstung, umfassend eine GME-Simultanmesseinheit (1) mit sechs Freiheitsgraden, DOF (degree of freedom), mit zwei Messstrahlen, eine strahlumlenkenden Einheit (2) und eine fehlersensitive Einheit (3),
wobei die 6-DOF-GME-Simultanmesseinheit (1) und die strahlumlenkende Einheit (2) auf einem Spannwerkstück montierbar sind, während die fehlersensitive Einheit (3) auf einem Spannwerkzeug montierbar ist,
wobei die 6-DOF-GME-Simultanmesseinheit (1) dazu ausgebildet ist, mit der fehlersensitiven Einheit (3) zusammenzuwirken, um die GME mit 6 DOF einer einzelnen Achse der präzisen Bearbeitungs- und Messausrüstung simultan oder individuell zu messen,
wobei die 6-DOF-GME-Simultanmesseinheit (1) einen Doppelfrequenzlaser (101) zum Bereitstellen eines einzelnen Doppelfrequenzlaserstrahls, Lambda-1/4-Plättchen (102, 107), Polarisationsstrahlteiler (103, 106) zum Teilen des einzelnen Strahls in zwei Messstrahlen, Strahlteiler (104, 108, 109), ein Rückstrahlelement (105), Strahlreflektorelemente (110, 114), Detektoren (111, 112, 113, 116, 118) und Linsen (115, 117) umfasst,
wobei die strahlumlenkende Einheit (2) dazu ausgebildet ist, die Messstrahlen von der 6-DOF-GME-Simultanmessinheit (1) zu teilen oder in geeigneter Reihenfolge in X-, Y- und Z-Richtung umzulenken und die reflektierten Messstrahlen von der fehlersensitiven Einheit (3, 301, 302) zu teilen oder zur 6-DOF-GME-Simultanmesseinheit (1) umzulenken, um dazu ausgebildet zu sein, die GME mit 6 DOF jeder entsprechenden Achse simultan zu messen,
wobei die 6-DOF-fehlersensitive Einheit (3) zwei Rückstrahlelemente (3011, 3012, 3021, 3022) und ein strahlteilendes Element (3013, 3023) umfasst,
wobei die Rückstrahlelemente (3011, 3012, 3021, 3022) sensitiv für den Positionsfehler, den horizontalen Geradheitsfehler und den vertikalen Geradheitsfehler einer linearen Bewegungsachse sind,
wobei das strahlteilende Element (3013, 3023) sensitiv für die Neigung und die Gierung der linearen Bewegungsachse ist,
wobei eine Kombination der zwei Rückstrahlelemente (3011, 3012, 3021, 3022) sensitiv für das Rollen der linearen Bewegungsachse ist,
wobei ein Würfel-Eck-Reflektor zur Verwendung als jedes der Rückstrahlelemente eingerichtet ist
und wobei ein Planstrahlteiler zur Verwendung als das strahlteilende Element eingerichtet ist und
wobei die Rechtwinkligkeitsfehler zwischen den drei Achsen aus den Geradheitsfehlern der drei Achsen errechenbar sind.

2. System nach Anspruch 1, wobei die fehlersensitive Einheit (3) drei wechselseitig rechtwinklige 6-DOF-fehlersensitive Einheiten (301, 302, 303) umfasst, welche jeweils für die 6-DOF-GME der drei wechselseitig rechtwinkligen linearen Bewegungsachsen (X, Y, Z) der Ausrüstung sensitiv sind.

3. System nach Anspruch 1, wobei die strahlumlenkende Einheit (2) ein strahlumlenkendes Prisma (2011) oder eine Kombination aus einem strahlteilenden Prisma (2021, 2022) und einem strahlumlenkenden Prisma umfasst,
wobei das strahlumlenkende Prisma, welches ein Polygonprisma oder ein Rechteckprisma einschließt, durch Translation und Rotation dazu ausgebildet ist, den Messstrahl von der 6-DOF-GME-Simultanmesseinheit (1) in die Richtungen, die parallel zu den drei linearen Bewegungsachsen der Ausrüstung sind, in getrennten Schritten umzulenken,
wobei die Kombination aus dem strahlteilenden Prisma und dem strahlumlenkenden Prisma eine Kombination aus zwei strahlteilenden Polygonprismen oder eine Kombination aus zwei strahlteilenden Rechteckprismen ist,
wobei der Strahl von der 6-DOF-GME-Simultanmesseinheit (1) dazu ausgebildet ist, sich simultan in drei wechselseitig rechtwinklige Strahlen aufzuteilen, die parallel zu den drei linearen Bewegungsachsen der Ausrüstung sind.

Revendications

1. Système de mesure par laser pour mesurer jusqu'à 21 erreurs géométriques de mouvement, GME, d'un équipement d'usinage et de mesure précis, comprenant une unité de mesure simultanée de GME (1) sur 6 degrés de liberté, DOF, ayant deux faisceaux de mesure, une unité de rotation de faisceau (2) et une unité sensible aux erreurs (3), dans lequel
l'unité de mesure simultanée de GME (1) sur 6 DOF et l'unité de rotation de faisceau (2) sont aptes à être montées sur une pièce de fabrication à serrer, tandis que l'unité sensible aux erreurs (3) est apte à être montée sur un outil de serrage ;
l'unité de mesure simultanée de GME (1) sur 6 DOF est adaptée pour coopérer avec l'unité sensible aux erreurs (3) pour mesurer simultanément ou individuellement les GME de 6 DOF d'un unique axe de l'équipement d'usinage et de mesure précis ; l'unité de mesure simultanée de GME (1) sur 6 DOF comprend un laser à double fréquence (101) pour fournir un unique faisceau laser à double fréquence, des lames quart d'onde (102, 107), des séparateurs de faisceau de polarisation (103, 106) pour diviser le

faisceau unique en deux faisceaux de mesure, des séparateurs de faisceau (104, 108, 109), un élément catadioptrique (105), des éléments de réflexion de faisceau (110, 114), des détecteurs (111, 112, 113, 116, 118) et des lentilles (115, 117) ;
l'unité de rotation de faisceau (2) est adaptée pour séparer ou faire tourner les faisceaux de mesure provenant de l'unité de mesure de GME (1) sur 6 DOF vers les directions X, Y et Z dans le bon ordre, et est conçue pour séparer ou faire tourner les faisceaux de mesure réfléchis provenant de l'unité sensible aux erreurs (3, 301, 302) vers l'unité de mesure de GME (1) sur 6 DOF, afin d'être adaptée pour mesurer simultanément les erreurs géométriques sur 6 DOF de chaque axe correspondant ;
l'unité sensible aux erreurs (3) sur 6 DOF comprend deux éléments catadioptriques (3011, 3012 ; 3021, 3022) et un élément de séparation de faisceau (3013, 3023) ; les éléments catadioptriques (3011, 3012 ; 3021, 3022) étant sensibles à l'erreur de position, à l'erreur de rectitude horizontale et à l'erreur de rectitude verticale d'un axe de mouvement linéaire ; l'élément de séparation de faisceau (3013, 3023) étant sensible au tangage et au lacet de l'axe de mouvement linéaire ; une combinaison des deux éléments catadioptriques (3011, 3012 ; 3021, 3022) étant sensible au roulis de l'axe de mouvement linéaire ; un réflecteur coin de cube est adapté pour être utilisé pour chaque élément catadioptrique, et un séparateur de faisceau plan est adapté pour être utilisé en tant qu'élément de séparation de faisceau ; et
les erreurs de perpendicularité entre les trois axes sont calculables à partir des erreurs de rectitude des trois axes.

2. Système selon la revendication 1, dans lequel l'unité sensible aux erreurs (3) comprend trois composants sensibles aux erreurs (301, 302, 303) sur 6 DOF mutuellement perpendiculaires, qui sont sensibles aux GME sur 6 DOF des trois axes de mouvement linéaire mutuellement perpendiculaires (X, Y, Z) de l'équipement, respectivement.

3. Système selon la revendication 1, dans lequel l'unité de rotation de faisceau (2) comprend un prisme de rotation de faisceau (2011), ou une combinaison d'un prisme de séparation de faisceau (2021, 2022) et d'un prisme de rotation de faisceau ; par translation et rotation, le prisme de rotation de faisceau, qui inclut un prisme polygonal ou un prisme rectangulaire, est adapté pour faire tourner le faisceau de mesure provenant de l'unité de mesure de GME (1) sur 6 DOF vers les directions qui sont parallèles aux trois axes de mouvement linéaires de l'équipement dans des étapes distinctes ; la combinaison du prisme de séparation de faisceau et du prisme de rotation de faisceau est une combinaison de deux prismes polygonaux de séparation de faisceau, ou une combinaison de deux prismes rectangulaires de séparation de faisceau, le faisceau provenant de l'unité de mesure de GME (1) sur 6 DOF est adapté pour se séparer simultanément en trois faisceaux mutuellement perpendiculaires, qui sont parallèles aux trois axes de mouvement linéaire de l'équipement.

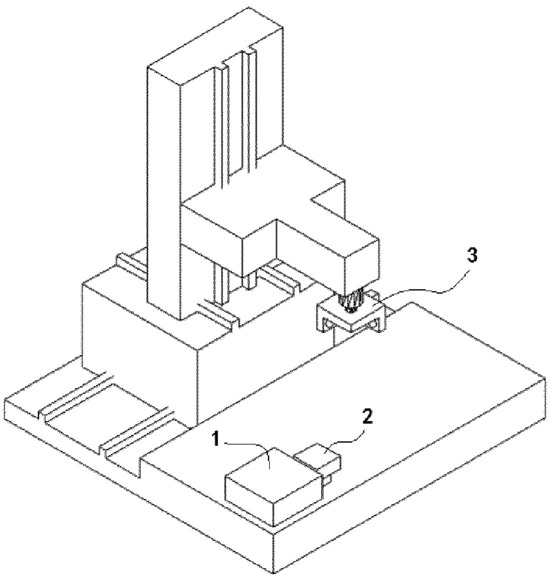

Fig. 1

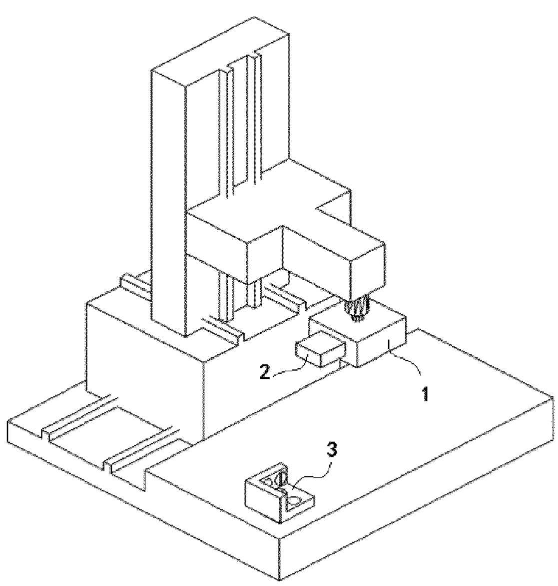

Fig. 2

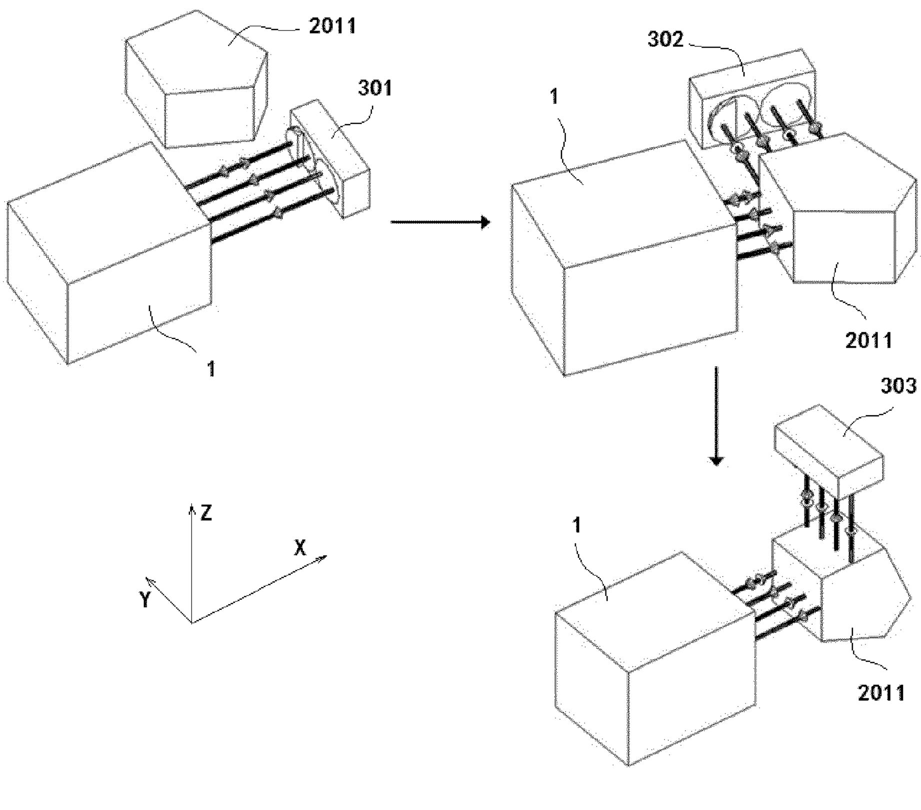

Fig. 3

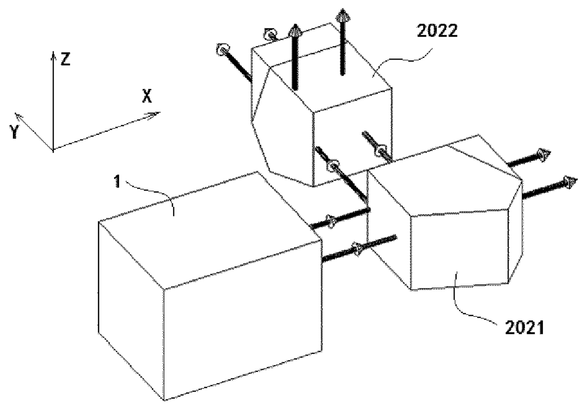

Fig. 4

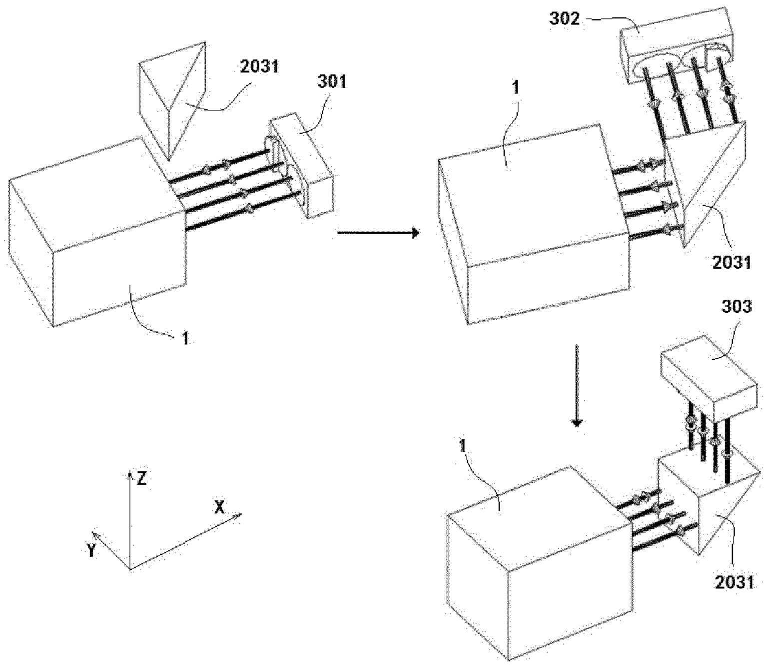

Fig. 5

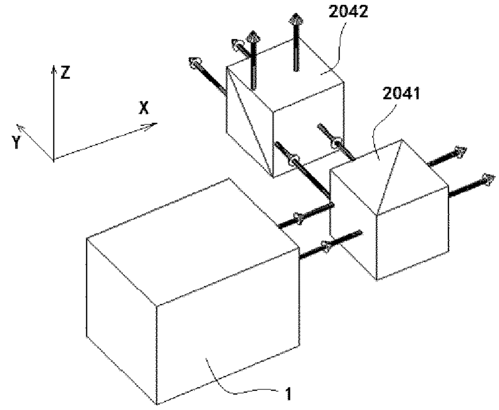

Fig. 6

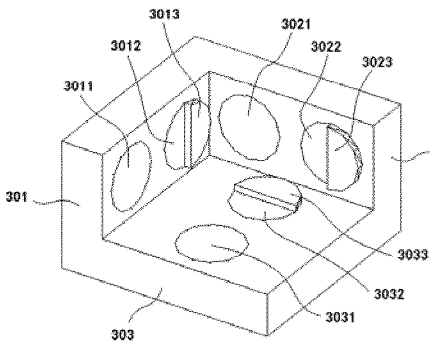

Fig. 7

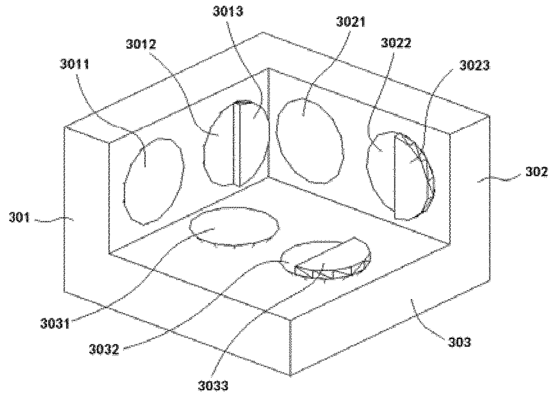

Fig. 8

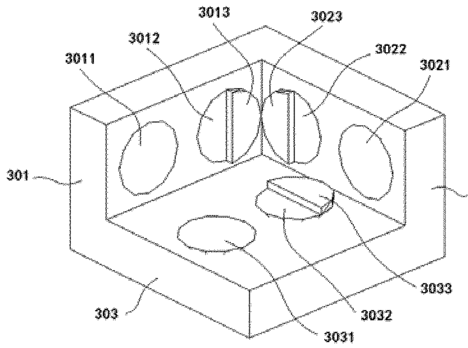

Fig. 9

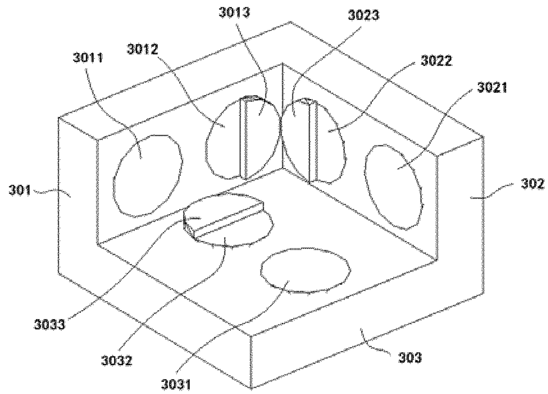

Fig. 10

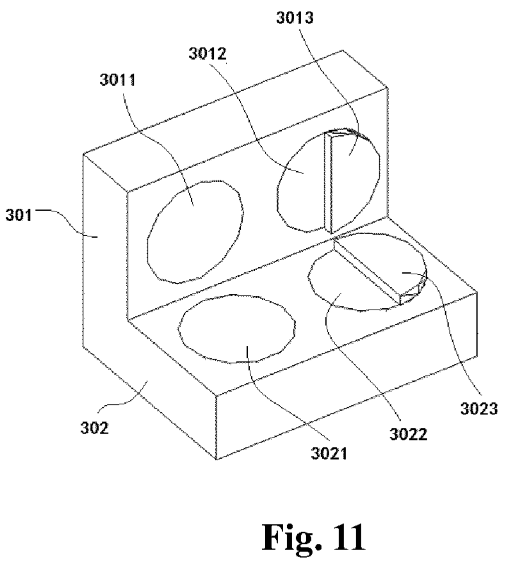

Fig. 11

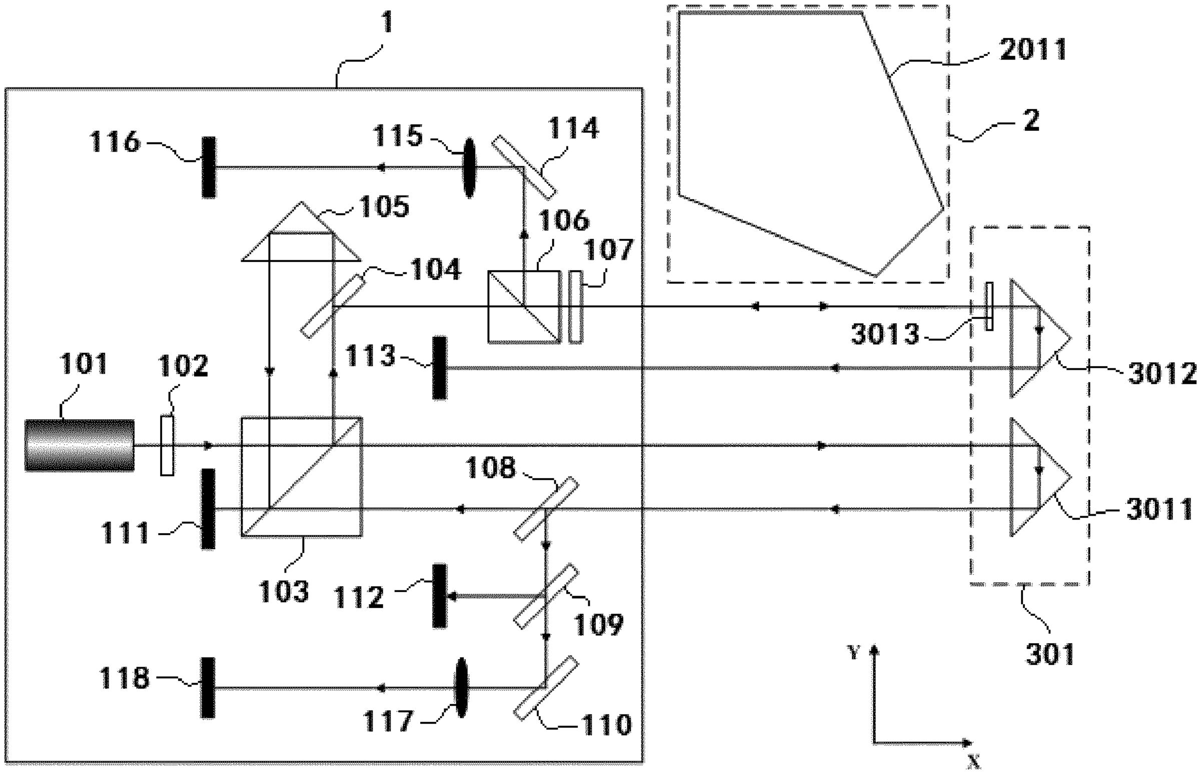
1
2011
2
116
115
114
105
106
107
104
3013
3012
113
101
102
108
111
3011
103
112
109
301
118
117
110
Y
X

Fig. 12

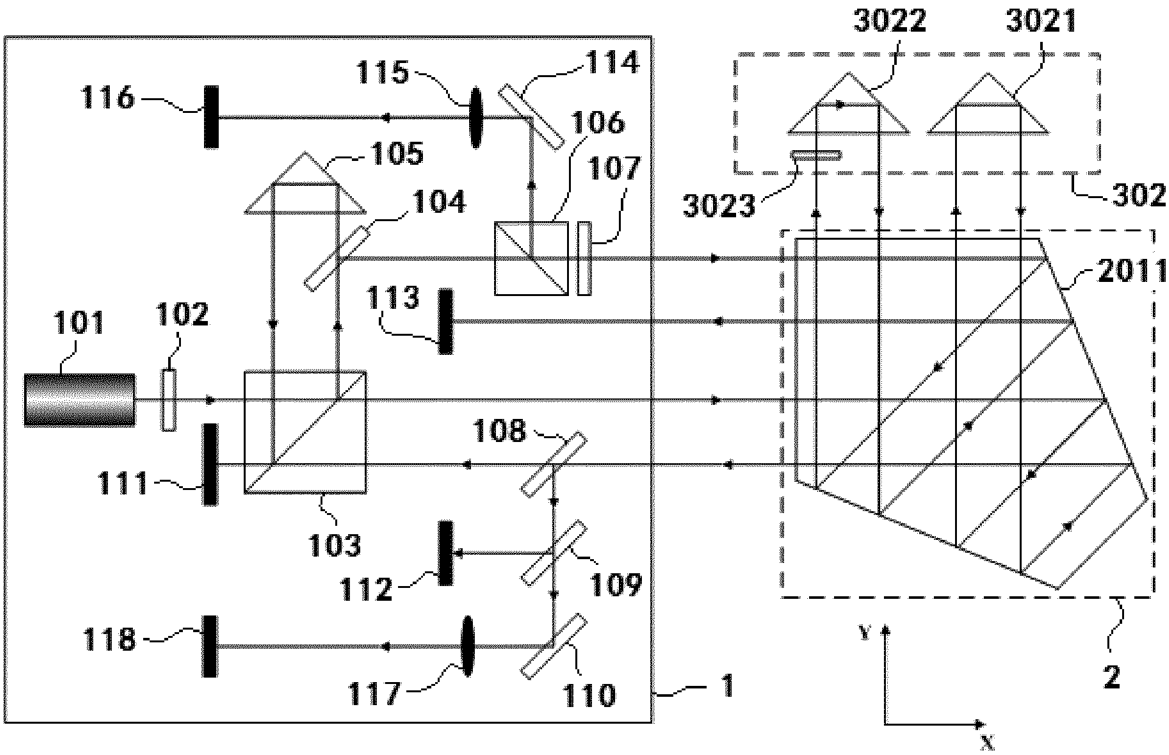
3022
3021
114
115
116
106
105
107
104
3023
302
113
2011
101
102
108
111
103
112
109
118
117
110
1
2
Y
X

Fig. 13

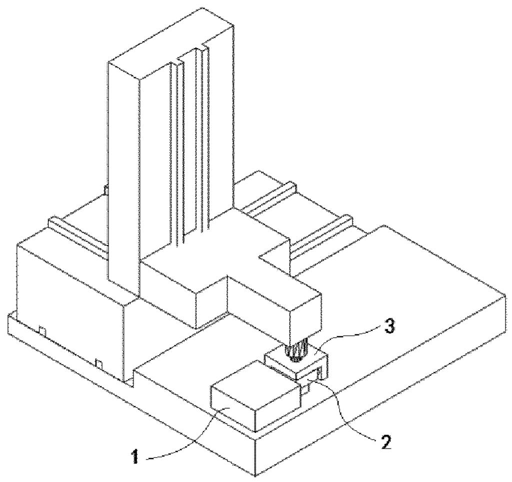

Fig. 14

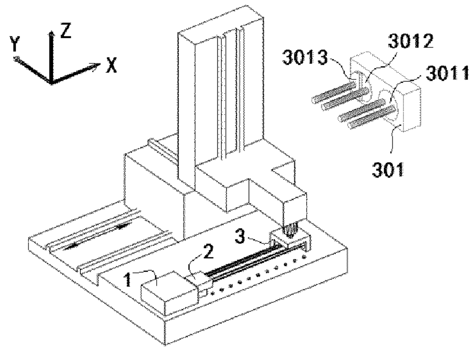

Fig. 15

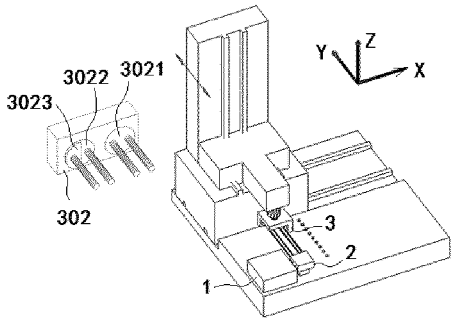

Fig. 16

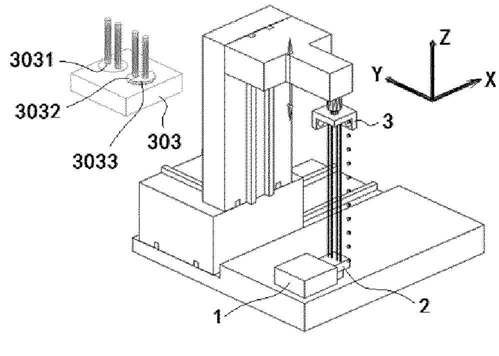

Fig. 17

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- DE 10341594 A1 **[0003]**
- CN 2884141 Y **[0005]**
- US 4939678 A **[0006]**