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(54) **PRECISE CALIBRATION APPARATUS AND METHOD FOR MAGNETORHEOLOGICAL POLISHING DEVICE**

(57) The present disclosure provides a precision calibrating device and a precision calibrating method for a magnetorheological polishing device, which realize an automatic and quick calibration process. It is ensured that a polishing gap is kept within an allowable error range when the magnetorheological polishing device processes surfaces of different optical elements, thereby effectively controlling a removal function, reducing or eliminating surface residual errors after processing and low frequency errors and medium frequency errors introduced by insufficient trajectory precision of a mechanical arm, and improving a processing precision of the magnetorheological polishing device based on the mechanical arm.

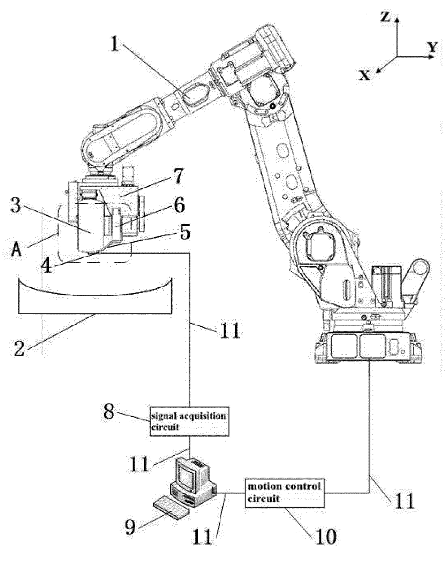

Fig. 1

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Description

[0001] The present application claims foreign priority to Chinese Patent Application No. 202010704882.5, titled: PRECISION CALIBRATING DEVICE FOR MAGNETORHEOLOGICAL POLISHING DEVICE AND METHOD THEREOF, filed on July 21, 2021 in the State Intellectual Property Office of China, and the entire contents of which is hereby incorporated by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to a technical field of magnetorheological polishing devices, and in particular to a precision calibrating device for a magnetorheological polishing device and a method thereof.

BACKGROUND

[0003] A motion carrier of a conventional magnetorheological polishing device is generally a multi-axis linkage-based computerised numerical control (CNC) machining center. With development of technology, a magnetorheological polishing module can be integrated on a mechanical arm, i.e., the mechanical arm is acted as the motion carrier of the magnetorheological polishing device. The mechanical arm has advantages of high motion speed and acceleration, flexible motion, and high processing efficiency. In addition, the mechanical arm costs much less than a multi-axis linkage-based CNC machining center for the same range of machining and has a smaller footprint.

[0004] However, compared with a multi-axis linkage-based CNC machine tool, the mechanical arm has disadvantage of low precision of a trajectory, i.e., a tail end of the mechanical arm is unable to accurately move along a predetermined trajectory in an optical processing process. An error of the precision of the trajectory reaches sub-millimeter level. A precision of a trajectory of the multi-axis linkage-based CNC machine tool with high precision is generally an order of magnitude higher than the mechanical arm. The reason for the low precision of the trajectory of the mechanical arm is closely related to a multi-joint tandem structure of the mechanical arm, making a polishing gap between a magnetorheological polishing wheel and a surface of a workpiece unstable or uncontrollably changing, which in turn leads to unstable or unpredictable changes in a removal function, and finally shows up as limitations on a processing precision of the magnetorheological polishing device based on the mechanical arm. Therefore, surface residual errors after processing contain typical low and medium frequency errors introduced by the mechanical arm.

[0005] Therefore, when processing various optical elements by the magnetorheological polishing device, how to make the polishing gap to maintain within an allowable error range is an urgent technical problem for those skilled in the art.

SUMMARY

[0006] A purpose of the present disclosure is to provide a precision calibrating device for a magnetorheological polishing device, which effectively improves a processing precision of the magnetorheological polishing device. Another purpose of the present disclosure is to provide a precision calibrating method for the magnetorheological polishing device.

[0007] To realize above purposes, the present disclosure provides the precision calibrating device for the magnetorheological polishing device.

[0008] The magnetorheological polishing device comprises a polishing wheel and a support base configured to mount the polishing wheel. The precision calibrating device comprises an arc-shaped support bracket, a sensor, a signal acquisition module, an industrial personal computer (IPC), and a motion control module.

[0009] The arc-shaped support bracket is detachably connected with the support base. The arc-shaped support bracket defines an arc-shaped surface attached to the polishing wheel. The sensor is fixed on the arc-shaped support bracket. The sensor is configured to detect a polishing gap.

[0010] The signal acquisition module is connected with the sensor. The IPC is connected with the signal acquisition module and the motion control module. The motion control module is connected with a control system of the magnetorheological polishing device. The IPC is configured to send an instruction to the signal acquisition module and the motion control module. The signal acquisition module is configured to control the sensor to acquire data. The motion control module is configured to send the instruction to the control system, so that the polishing wheel moves along a predetermined processing trajectory.

[0011] Optionally, the sensor is a displacement sensor or a pressure sensor.

[0012] Optionally, the arc-shaped support bracket defines a through hole. An effective working hole of the sensor coincides with the through hole. A center of the effective working hole of the sensor coincides with a vertex of a spherical crown of the polishing wheel.

[0013] Optionally, an adjusting bracket is arranged on the arc-shaped support bracket. Strip-shaped holes configured to adjust a height of the adjusting bracket are defined on the adjusting bracket. Fasteners pass through the strip-shaped holes to fix the adjusting bracket to the support base.

[0014] Optionally, the adjusting bracket defines two strip-shaped holes parallel to each other.

[0015] The precision calibrating method for the magnetorheological polishing device comprises:

mounting an optical element to be processed on the magnetorheological polishing device, and aligning a coordinate system of the optical element to be processed with a processing coordinate system;

mounting an arc-shaped support bracket of a precision calibrating device on a support base of a polishing wheel;

controlling a sensor to collect displacement values between the sensor and the optical element to be processed, and controlling the polishing wheel to move along a predetermined processing trajectory;

obtaining error values between the displacement values and predetermined values;

determining whether the error values satisfy a precision requirement;

if yes, compensating the error values into the predetermined processing trajectory of the magnetorheological polishing device;

if not, correcting the predetermined processing trajectory according to the error value; and

obtaining the error values between the displacement values and the predetermined values again according to a corrected predetermined processing trajectory.

[0016] Optionally, a step of controlling the sensor to collect the displacement values between the sensor and the optical element to be processed and controlling the polishing wheel to move along the predetermined processing trajectory comprises:

sending an instruction to a signal acquisition circuit and a motion control circuit through an IPC; controlling the sensor to collect data through the signal acquisition circuit; sending the instruction to a control system of the magnetorheological polishing device and the motion control circuit, so that the polishing wheel moves along the predetermined processing trajectory.

[0017] Optionally, a step of obtaining the error values between the displacement values and the predetermined values comprises:

processing the data collected by the sensor by the IPC; comparing collected displacement values with the predetermined values to obtain the error values.

[0018] Optionally, the error values comprise low frequency errors, medium frequency errors, and high frequency errors.

[0019] In the precision calibrating device for the magnetorheological polishing device of the present disclosure, when precision calibration is required, the arc-shaped support bracket with the sensor is mounted on the support base. The sensor of the present disclosure is mounted in such a way that a distance between the polishing wheel and the optical element to be processed is very short when the precision is calibrated. The distance between the polishing wheel and the optical element corresponds to the polishing gap in millimeter scale during actual processing, which effectively ensures a calibration precision and a precision during actual use. After the calibration is completed, the arc-shaped support bracket with the sensor is detached from the support base. Then the optical element to be processed is processed by the magnetorheological polishing device.

[0020] In the precision calibrating method for the magnetorheological polishing device of the present disclosure, a data collection process of the precision calibrating device and a motion of the mechanical arm are synchronized, which effectively ensures that the data measured is corresponding to a motion position of the mechanical arm and ensures validity of the data. By executing the precision calibrating method, errors in all frequency bands that affect the polishing gap are measured, and the low frequency errors, the medium frequency errors, and the high frequency errors in a system are effectively compensated, thereby improving the precision of the magnetorheological polishing device. Further, the errors directly measured are converted into polishing gap errors in an actual processing process. Therefore, it is easy to obtain an actual processing code with significantly improved precision of the trajectory of the magnetorheological polishing device after the errors are compensated.

BRIEF DESCRIPTION OF DRAWINGS

[0021] In order to clearly describe technical solutions in the embodiments of the present disclosure, the following will briefly introduce the drawings that need to be used in the description of the embodiments or the prior art. Apparently, the drawings in the following description are merely some of the embodiments of the present disclosure, and those skilled in the art are able to obtain other drawings according to the drawings without contributing any inventive labor. In the drawing:

FIG 1 is a schematic diagram of a precision calibrating device and a magnetorheological polishing device according to one embodiment of the present disclosure.

FIG 2 is an enlarged schematic diagram of area A shown in FIG 1.

FIG 3 is a schematic diagram of the area A shown in FIG 2 where the precision calibrating device is removed.

FIG 4 is a schematic diagram of the area A shown in FIG 2 that views from a Y direction.

FIG 5 is a schematic diagram of the area A shown in FIG 2 that views from a Z direction.

[0022] In the drawings:

1-mechanical arm, 2 - optical element, 3 - polishing wheel, 4 - sensor, 5 - arc-shaped support bracket, 6 - adjusting bracket, 7 -support base, 8 - signal acquisition circuit, 9 -IPC, 10 - motion control circuit, 11 - power cable, 12 - through hole.

DETAILED DESCRIPTION

[0023] In order to make purposes, features, and advantages of the present disclosure obvious and understandable, a detailed description of specific embodiments of the present disclosure is given below in connection with accompanying drawings.

[0024] Specific details are set forth in the following description to facilitate a full understanding of the present disclosure. However, the present disclosure can be implemented in a variety of ways than those described herein, and those skilled in the art may make similar extensions without contradicting the context of the present disclosure. The present disclosure is therefore not limited by the specific embodiments disclosed below.

[0025] As shown in FIGS. 1-5, FIG 1 is a schematic diagram of a precision calibrating device and a magnetorheological polishing device according to one embodiment of the present disclosure, FIG 2 is an enlarged schematic diagram of area A shown in FIG 1, FIG 3 is a schematic diagram of the area A shown in FIG 2 where the precision calibrating device is removed, FIG 4 is a schematic diagram of the area A shown in FIG 2 that views from a Y direction, and FIG 5 is a schematic diagram of the area A shown in FIG 2 that views from a Z direction.

[0026] In one specific embodiment, the present disclosure provides the precision calibrating device for the magnetorheological polishing device. The magnetorheological polishing device comprises a polishing wheel 3 and a support base 7 configured to mount the polishing wheel 3. The precision calibrating device comprises an arc-shaped support bracket 5, a sensor 4, a signal acquisition module, an industrial personal computer (IPC), and a motion control module. The arc-shaped support bracket 5 defines an arc-shaped surface. The sensor 4 is fixed on the arc-shaped support bracket 5. Optionally, the sensor 4 is a displacement sensor 4 or a pressure sensor 4. The pressure sensor determines a size of a polishing gap by measuring a contact force.

[0027] The signal acquisition module is connected with the sensor 4 through signals and a power cable 11. The IPC 9 is connected with the signal acquisition module and the motion control module through the signals and the power cable 11. The motion control module is connected with a control system of the magnetorheological polishing device through the signals and the power cable 11. When it is necessary to calibrate a precision, the arc-shaped support bracket 5 with the sensor 4 is mounted on the support base 7, and a surface of the arc-shaped support bracket 5 contacting the polishing wheel 3 is defined as the arc-shaped surface. A curvature radius of the arc-shaped surface of the arc-shaped support bracket 5 is same as a curvature radius of the polishing wheel 3. The arc-shaped support bracket 5 defines a through hole 12. An effective working hole of the sensor 4 coincides with the through hole 12. A center of the effective working hole of the sensor 4 coincides with a vertex of a spherical crown of the polishing wheel 3. The effective working hole of the sensor 4 is ensured to coincide with the through hole 12 by following implements:

a. ensuring that the effective working hole of the sensor 4 coincides with the through hole 12 as far as possible during mechanical design. Meanwhile, ensuring that the arc-shaped support bracket 5 completely fits with the polishing wheel 3 and ensuring that the sensor 4 is mounted in a specific position.
b. after the precision calibrating device is mounted on the magnetorheological polishing device, the magnetorheological polishing device is calibrated by a coordinate measuring device such as a coordinate measuring machine (CMM) or a laser trajectoryer.
c. performing effective error compensation.

[0028] The sensor 4 of the present disclosure is mounted in such a way that a distance between the polishing wheel 3 and the optical element 2 to be processed is very short when the precision is calibrated. The distance between the polishing wheel 3 and the optical element 2 to be processed corresponds to the polishing gap in millimeter scale during actual processing, which effectively ensures a calibration precision and a precision during actual use. It is understood that a position posture of each joint of the mechanical arm 1 in a precision calibration state and the position posture of each joint of the mechanical arm 1 in an actual processing state are consistent, which effectively improves a precision of the polishing gap during the actual processing. After the calibration is completed, the arc-shaped support bracket 5 with the sensor 4 is detached from the support base 7. That is, once the precision is calibrated for a first time, a position of each sub-component does not need to be re-calibrated when used again. When in precision calibration, the IPC 9 sends an instruction to the signal acquisition module and the motion control module. The signal acquisition module controls the sensor to collect data. At the same time, the motion control module sends the instruction to the control system, so that the polishing wheel 3 is controlled to move along a predetermined processing trajectory. Data collected by the sensor 4 is processed in the IPC 9, and displacement values collected by the sensor4 are compared with predetermined values to obtain error values. Then it is determined whether the error values meet a precision requirement. If not, the predetermined processing trajectory is compensated according to the error values, and the error values are continuously obtained until the pre0cision requirement is met and when current error values meets the precision requirement, the current error values are compensated into the predetermined processing trajectory of the magnetorheological polishing device to complete the precision calibration. After the precision calibrating device is removed, the magnetorheological polishing device is applied to process the optical element 2.

[0029] Furthermore, an adjusting bracket is arranged on the arc-shaped support bracket 5. Strip-shaped holes are defined on the adjusting bracket. Optionally, two strip-shaped holes parallel to each other are provided. Fasteners pass through the strip-shaped holes to fix the adjusting bracket to the support base 7. A height of the adjusting bracket is adjusted by the strip-shaped holes, so a height of the sensor 4 is adjusted accordingly.

[0030] One specific embodiment of the present disclosure further provides a precision calibrating method for the magnetorheological polishing device. The precision calibrating method comprises:

Step 1: pre-aligning an optical element;
The optical element 2 to be processed is mounted on the magnetorheological polishing device. The optical element 2 to be processed may be flat, spherical, aspherical, free-form, convex, concave, etc. The optical element 2 to be processed may be made of various materials such as optical glass, SiC ceramics, alloys, etc., and may be either reflective or lenticular. A coordinate system of the optical element 2 to be processed is aligned with a processing coordinate system by existing method.
Step 2: mounting a precision calibrating device;
The arc-shaped support bracket 5 of the precision calibrating device is mounted on the support base 7 of the polishing wheel 3. Specifically, the precision calibrating device provided by the above embodiments is first assembled. When designing, the center of the effective working hole of the sensor 4 is made to be located at the vertex of the spherical crown of the magnetorheological polishing wheel 3 as far as possible; An adjustment amount is reserved after a hardware design is completed, and the magnetorheological polishing device is calibrated by the coordinate measuring device such as a CMM with high-precision or the laser trajectoryer with high-precision. Once the calibration is completed, the sensor 4 and the arc-shaped support bracket 5 are no longer disassembled and relative positions thereof are fixed. The adjusting bracket 6 is dechably connected to the support base 7 in a resettable way through quick disassembly or quick assembly of the adjusting bracket 6, so a position of the effective working hole of the sensor 4 does not need to be calibrated again in a subsequent processing of other optical elements.
Step 3: planning a processing trajectory;
A processing trajectory that is reasonable is determined according to geometric parameters, an initial surface error, etc. of the optical element 2 to be processed. The processing trajectory may be a raster-scanning processing trajectory, a spiral processing trajectory, a concentric-circle processing trajectory, or other complex trajectory such as a random processing trajectory.
Step 4: generating an executing code executed by the mechanical arm;
In the step, the processing trajectory is converted into the executing code executed by the mechanical arm 1 through combining geometric parameters of the optical element 2 to be processed and motion axis parameters of the magnetorheological polishing device. The executing code must satisfy:

1, Without considering a motion precision of the mechanical arm 1, ensuring that a distance between the sensor 4 mounted on the polishing wheel 3 and a surface of the optical element 2 to be processed is as close as possible, i.e., the distance between the sensor 4 and the surface of the optical element 2 to be processed is within an effective working range, and the distance between the sensor 4 and the surface of the optical element 2 to be processed is kept consistent in different areas of a full aperture of the optical element 2 to be processed. The distance between the sensor 4 and the surface of the optical element 2 to be processed corresponds to the polishing gap.
2, Setting speeds between residual points on the processing trajectory. Specifically, the speeds between all of the residual points are same, that is, the mechanical arm 1 drives a magnetorheological polishing module to move uniformly. Alternatively, the speeds between the residual points may be different, or the speeds may be speeds converted by actual residual time calculated according to an actual surface error of the optical element to be processed. The motion speed in the executing code executed by the mechanical arm 1 is adjustable, ensuring that a calibration process is shortened and an occupation of an actual processing period is reduced.

Step 5: turning on the mechanical arm for operation;
The executing code in step 4 is imported into the motion control module of the mechanical arm 1 by the IPC 9, and the mechanical arm 1 is turned on and is adjusted to a pending operation state.
Step 6: setting parameters of the precision calibrating device;
Specifically, parameters of the sensor 4 of the precision calibrating device is set, and a sampling frequency, an operating range, a dynamic range, etc. of the sensor 4 are set in the IPC 9.
Step 7: turning on the precision calibrating device for operation;
Specifically, a signal acquisition circuit 8 and the sensor 4 of the precision calibrating device are turned on and adjusted to the pending operation state.
Step 8: synchronously operating the precision calibrating device and the magnetorheological polishing device;
Specifically, the IPC 9 respectively sends the instruction to the signal acquisition circuit 8 and the motion control circuit 10. The signal acquisition circuit 8 controls the sensor 4 to collect data, while the motion control circuit 10 sends the instruction to the control system of the mechanical arm 1, and the mechanical arm 1 moves according to the executing code in step 4. That is, a synchronous operation of the precision

calibrating device and the magnetorheological polishing device is realized in the step, which should be operated under a same clock. Since data collection of the precision calibrating device is synchronized with the motion of the mechanical arm 1, it is effectively ensured that the data measured and motion positions of the mechanical arm 1 correspond to each other, which ensures the validity of the data measured.

Step 9: processing data

The data collected by the signal acquisition circuit 8 is processed in the IPC 9. Then the collected displacement values are compared with predetermined displacement theoretical values to get the error values. Different kinds of error values are extracted from the error values, including low frequency errors, medium frequency errors, and high frequency errors. The low frequency errors are generated due to misalignment, such as:

a. low-order errors generated by pre-alignment of the optical element to be processed in step 1;
b. low-order errors generated by non-coincidence of the effective working hole of the sensor 4 and the vertex of the spherical crown of the polishing wheel 3 in step 2.

An analysis of the data collected indicates that the data are represented in a form such as tilt, out-of-focus, image dispersion and comet aberration. The medium frequency errors are mainly generated during a motion process of the mechanical arm 1. The high frequency errors are mainly generated by vibration of the magnetorheological polishing device during the motion process. The low frequency errors, the medium frequency errors, and part of the high frequency errors (systematic errors) are extracted.

Step 10: compensating the errors;

Specifically, error compensation is performed on the low frequency errors, the medium frequency errors, and part of the high frequency errors extracted in step 9. That is, the processing trajectory of step 3 should consider the errors measured.

Step 11: correcting the executing code executed by the mechanical arm 1;

Specifically, according to the error compensation in step 10, combined with the geometric parameters of the optical element 2 to be processed and the motion axis parameters of the magnetorheological polishing device, the processing trajectory is converted into the executing code again.

Step 12: adjusting the mechanical arm for operation;

Specifically, the executing code in step 11 is automatically imported into the motion control circuit of the mechanical arm 1 by the IPC 9, and the mechanical arm 1 is adjusted to the pending operation state.

Step 13: setting the parameters of the precision calibrating device;

Specifically, the parameters of the sampling frequency, the operating range, the dynamic range in the IPC 9 is optimized according to a measurement result in step 10. Alternatively, the parameters set in step 6 are no need to be set again.

Step 14: adjusting the precision calibrating device for operation;

In the step, the signal acquisition circuit 8 and the sensor 4 are adjusted to the pending operation state by the IPC 9.

Step 15: synchronously operating the precision calibrating device and the magnetorheological polishing device;

The step is same as the step 8. Specifically, the IPC 9 respectively sends the instruction to the signal acquisition circuit 8 and the motion control circuit 10. The signal acquisition circuit 8 controls the sensor 4 to collect data, while the motion control circuit 10 sends the instruction to the control system of the mechanical arm 1, and the mechanical arm 1 moves according to the executing code in step 11. That is, a synchronous operation of the precision calibrating device and the magnetorheological polishing device is realized in the step, which should be operated under the same clock. The difference is that the executing code in the step 15 is the executing code in the step 11 after the error compensation.

Step 16: processing the data;

The data collected by the signal acquisition circuit 8 is processed again in the IPC 9. Then the collected displacement values are compared with the predetermined displacement theoretical values to get the error values.

Step 17: determining whether the error values satisfy a precision requirement;

[0031] In the step, the error values in the step 16 are compared with a required precision to determine whether the low frequency errors, the medium frequency errors, and the part of the high frequency errors (systematic errors) meet the requirements of the magnetorheological polishing device. The requirements of the magnetorheological polishing device are determined by requirements of the corresponding optical process on the polishing gap.

[0032] If the error values do not satisfy the precision requirement;, the predetermined processing trajectory is corrected according to the error values. Then the error values between the displacement values and the predetermined values are obtained again according to a corrected predetermined processing trajectory, i.e., the steps 10-16 are repeated. The precision calibrating device and the mechanical arm 1 are automatically and synchronously controlled by the IPC 9. After presetting of the parameters is completed, the key steps 10-17 of the error calibration are automated, which do not require manual participation.

[0033] If the error values satisfy the precision requirement, a next step is performed.

Step 18: compensating the error values into a processing code;

If the error values satisfy the precision requirement in the step 17, the step 18 is performed. The error values are compensated into the predetermined processing trajectory of the magnetorheological polishing device. In the step, the low frequency errors, the medium frequency errors, and the part of the high frequency errors in step 10 are accumulated and compensated into the processing code which is obtained by combining the processing trajectory and the actual residual time calculated according to the actual surface error of the optical element to be processed. It should be noted that the displacement values measured in steps 9 and 16 does not represent the real polishing gap, but the distance between the sensor 4 mounted on the polishing wheel 3 and the surface of the optical element 2 to be processed as mentioned in step 4. However, the displacement values are corresponding to the polishing gap. Therefore, when converting the executing code after the error compensation in the step, the difference between calibrated displacement values and the polishing gap should be considered, and a linear difference between the displacement values and the polishing gap is eliminated to obtain the actual processing code after compensation that ensures constant of the polishing gap.

Step 19: removing the precision calibrating device; and

In the step, after the step 18 is completed, the precision calibrating device is completely removed before an actual processing of the optical element 2 to be processed.

Step 20: processing the optical element 2 to be processed.

[0034] After completing all of above steps, the optical element 2 to be processed is processed by the magnetorheological polishing device.

[0035] In summary, the present disclosure provides the precision calibrating device and the precision calibrating method for the magnetorheological polishing device, which realize automatic and quick calibration process and ensure that the polishing gap is kept within an allowable error range when the magnetorheological polishing device processes surfaces of different optical elements, thereby effectively controlling the removal function, reducing or eliminating the surface residual errors after processing and the low frequency errors and the medium frequency errors introduced by insufficient trajectory precision of the mechanical arm 1, and improving a processing precision of the magnetorheological polishing device based on the mechanical arm 1. The present disclosure has at least followed advantages.

[0036] The present disclosure is able to calibrate a wide range of error frequency bands, so all of the frequency errors affecting the polishing gap are measured, of which the low frequency errors, the medium frequency errors, and the part of the high frequency errors (systematic errors) are effectively compensated, thereby improving the processing precision of the magnetorheological polishing device.

[0037] The present disclosure is highly applicable. The optical element 2 to be processed may be flat, spherical, aspherical, free-form, convex, concave, etc. The optical element 2 to be processed may be made of various materials such as the optical glass, the SiC ceramics, the alloys, etc. The precision calibrating device is not limited to be mounted on the magnetorheological polishing device, and other devices based on the mechanical arm or devices based on a multi-axis linkage-based CNC machine tool can directly adopt schemes of the preset disclosure or use the schemes of the preset disclosure as references for calibrating or improving the precision.

[0038] The calibration precision of the present disclosure is high. The precision of an existing displacement sensor 4 generally reaches the micron level. Based on the sensor 4, the present disclosure performs the error compensation through repeated iterations, which effectively improves the precision. The errors measured by the present disclosure are the displacement values corresponding to the required polishing gap, and there is a linear relationship between the displacement values and the polishing gap, which further ensures the calibration precision of the present disclosure. The trajectory of the mechanical arm 1 during the calibration process coincides with the trajectory during the actual processing, which ensures the consistency of calibration precision and the precision during actual use.

[0039] On a main aspect of improving the processing precision, the present disclosure improves an actual processing precision of the optical element 2 to be processed and improves the precision of the trajectory of the mechanical arm 1, so the polishing gap is constant. Thus, the stability of the removal function is ensured. On the other hand, the calibration steps of the present disclosure further compensate errors generated by misalignment of the optical element to be processed, which further improves the actual processing precision.

[0040] The present disclosure has a high calibration efficiency. Calibration hardware is quickly assembled and disassembled. A running speed of the mechanical arm 1 during executing the executing code is adjustable. Further, error measurement and iterative compensation process are relatively automatic.

[0041] The present disclosure applies to a wide range of structures. The present disclosure is not only applied to the structure where the optical element (a reflector 2) is arranged on a bottom position thereof and tools (a magnetorheological polishing module and the mechanical arm 13) are arranged at a top position thereof. The present disclosure can also be applied to other structures, such as a structure where a position of the reflector 2 is interchanged with a position of the magnetorheological polishing module (including the polishing wheel 3) in FIG 1. That is, the reflector is grasped by the mechanical arm 1 and is arranged above the mechanical arm and the magnetorheological polishing module is arranged below the reflector, i.e., the optical element is arranged on the top position thereof and the tools are arranged on the bottom position thereof. Except for the structure where the optical element is arranged on the bottom position and the tools are arranged at the top position or the structure where the optical element is arranged on the top position and the tools are arranged on the bottom position, a structure where the optical element and the tools are placed horizontally is also applied. All structures that conform to the principle of relationship between relative positions of the optical element and the tools in the present disclosure are applicable, which is not limited thereto.

[0042] In addition, the present disclosure ensures the stability of the removal function by ensuring that the polishing gap is constant. That is, a controllable change in the polishing gap is guaranteed to ensure a controllable change in the removal function. Based on the controllable change, the high precision processing of the optical element 2 is realized.

[0043] It should be noted that, in the present disclosure, relational terms, such as "first" and "second", are only used to distinguish one feature or operation from another feature or operation, and do not necessarily require or imply any actual relationship or sequence exists between these features or operations. Moreover, terms "comprise", "include" or any other variation thereof are intended to encompass non-exclusive inclusion, such that a process, method, article or device not only comprises elements explicitly listed, but also comprises elements not explicitly listed or other elements inherent to such a process, method, article, or device. Without further limitation, elements defined by the statement "including a ......" do not preclude the existence of additional identical elements in the process, method, article, or device including the elements.

[0044] Embodiments in the specification are described in a progressive manner, with each embodiment focusing on what is different from other embodiments, and same and similar parts between each embodiment can be cross-referenced.

[0045] The above description of the disclosed embodiments enables those skilled in the art to implement or use the present disclosure. A variety of modifications to these embodiments are apparent to those skilled in the art, and general principles defined in the specification can be implemented in other embodiments without departing from the spirit or scope of the present disclosure. Thus, the present disclosure should not be limited to the embodiments disclosed herein and should be subject to the widest scope consistent with the principles and novel features disclosed herein.

Claims

1. A precision calibrating device for a magnetorheological polishing device including a polishing wheel and a support base configured to mount the polishing wheel, comprising:

    an arc-shaped support bracket,
    a sensor,
    a signal acquisition module,
    an industrial personal computer (IPC), and
    a motion control module;
    wherein the arc-shaped support bracket is detachably connected with the support base; the arc-shaped support bracket defines an arc-shaped surface attached to the polishing wheel; the sensor is fixed on the arc-shaped support bracket; the sensor is configured to detect a polishing gap;
    wherein the signal acquisition module is connected with the sensor; the IPC is connected with the signal acquisition module and the motion control module; the motion control module is connected with a control system of the magnetorheological polishing device; the IPC is configured to send an instruction to the signal acquisition module and the motion control module; the signal acquisition module is configured to control the sensor to collect data; the motion control module is configured to send the instruction to the control system, so that the polishing wheel moves along a predetermined processing trajectory.

2. The precision calibrating device according to claim 1, wherein the sensor is a displacement sensor or a pressure sensor.

3. The precision calibrating device according to claim 1, wherein the arc-shaped support bracket defines a through hole; an effective working hole of the sensor coincides with the through hole; and a center of the effective working hole of the sensor coincides with a vertex of a spherical crown of the polishing wheel.

4. The precision calibrating device according to claim 1, wherein an adjusting bracket is arranged on the arc-shaped support bracket; strip-shaped holes configured to adjust a height of the adjusting bracket are defined on the adjusting bracket; fasteners pass through the strip-shaped holes to fix the adjusting bracket to the support base.

5. The precision calibrating device according to claim 4, wherein the adjusting bracket defines two strip-shaped holes parallel to each other.

6. A precision calibrating method for a magnetorheological polishing device, comprising:

mounting an optical element to be processed on the magnetorheological polishing device, and aligning a coordinate system of the optical element to be processed with a processing coordinate system;
mounting an arc-shaped support bracket of a precision calibrating device on a support base of a polishing wheel;
controlling a sensor to collect displacement values between the sensor and the optical element to be processed, and controlling the polishing wheel to move along a predetermined processing trajectory;
obtaining error values between the displacement values and predetermined values;
determining whether the error values satisfy a precision requirement;
if yes, compensating the error values into the predetermined processing trajectory of the magnetorheological polishing device;
if not, correcting the predetermined processing trajectory according to the error value; and
obtaining the error values between the displacement values and the predetermined values again according to a corrected predetermined processing trajectory.

7. The precision calibrating method according to claim 6, wherein a step of controlling the sensor to collect the displacement values between the sensor and the optical element to be processed and controlling the polishing wheel to move along the predetermined processing trajectory comprises:
sending an instruction to a signal acquisition circuit and a motion control circuit through an IPC; controlling the sensor to collect data through the signal acquisition circuit; sending the instruction to a control system of the magnetorheological polishing device and the motion control circuit, so that the polishing wheel moves along the predetermined processing trajectory.

8. The precision calibrating method according to claim 7, wherein a step of obtaining the error values between the displacement values and the predetermined values comprises:
processing the data collected by the sensor by the IPC; comparing a collected displacement values with the predetermined values to obtain the error values.

9. The precision calibrating method according to claim 8, wherein the error values comprise low frequency errors, medium frequency errors, and high frequency errors.

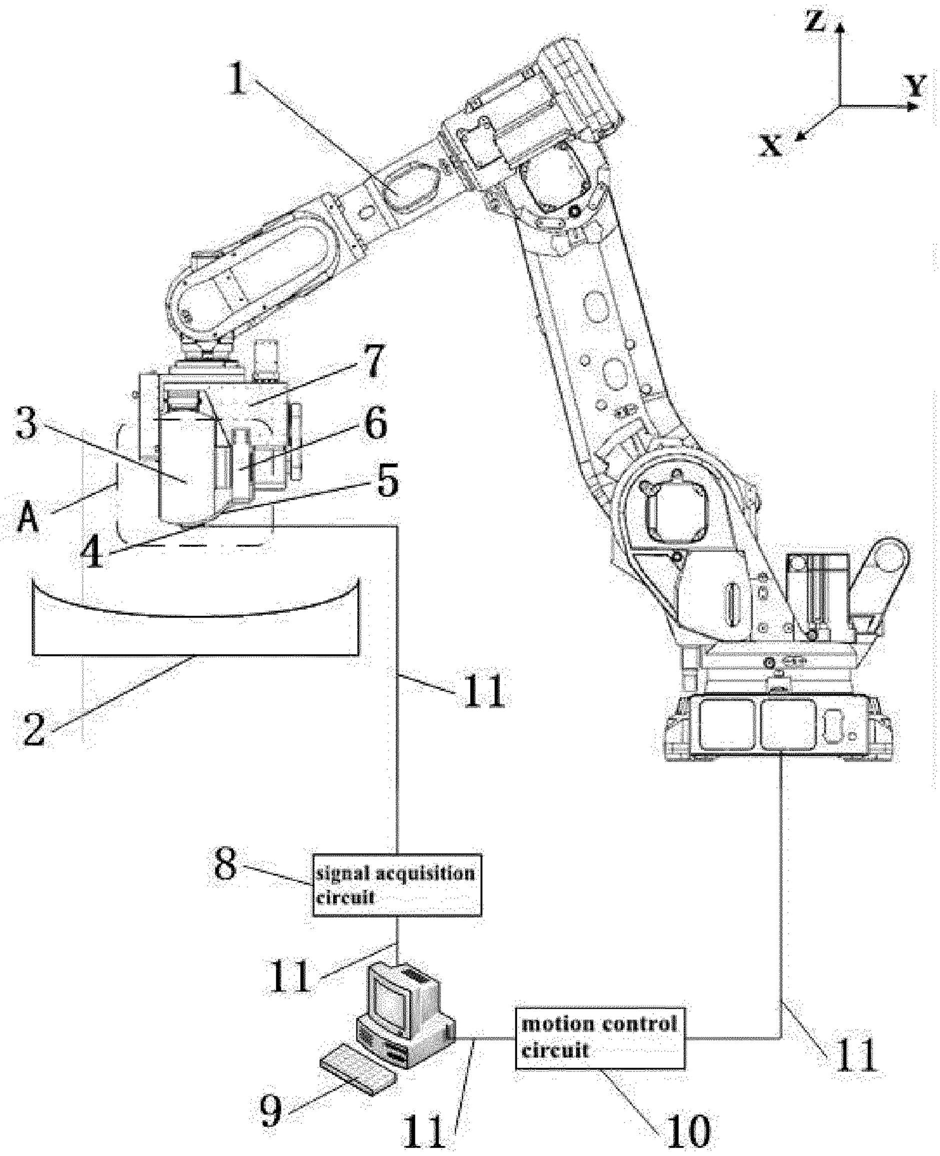
Z
Y
X
1
7
3
6
5
A
4
2
11
8
signal acquisition circuit
11
motion control circuit
11
9
11
10

Fig. 1

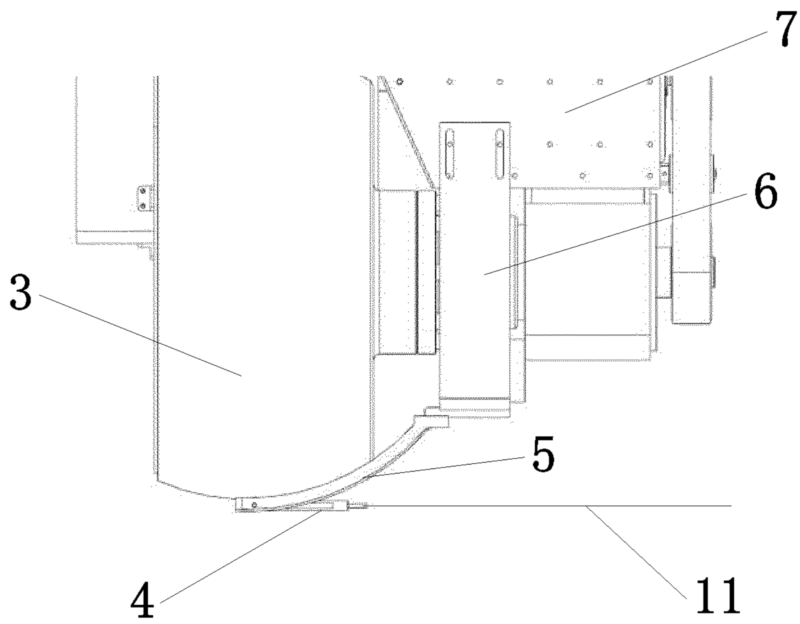

Fig. 2

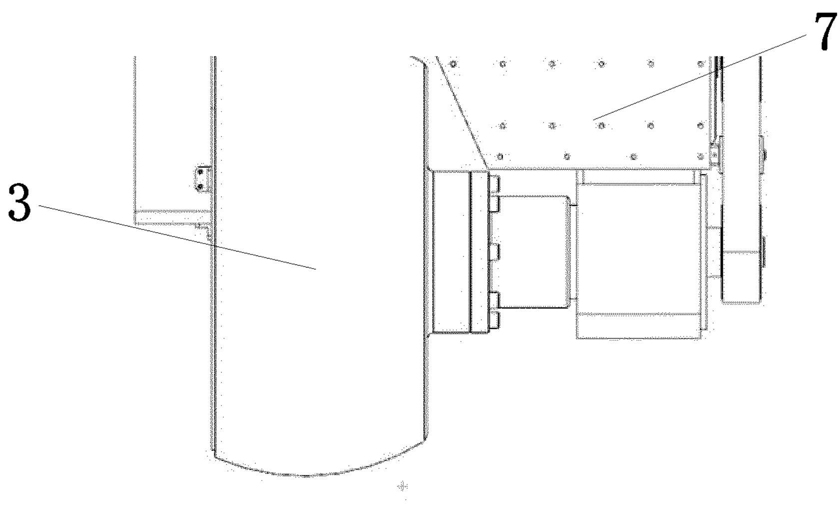

Fig. 3

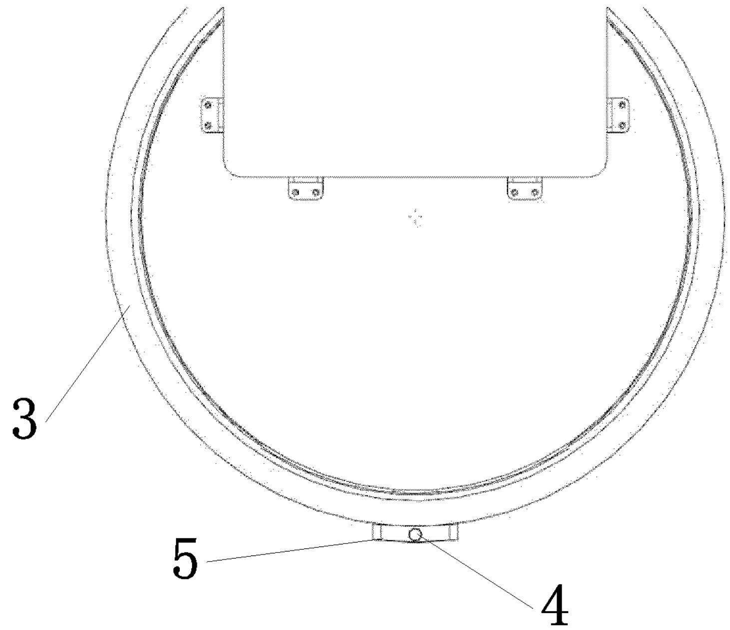

Fig. 4

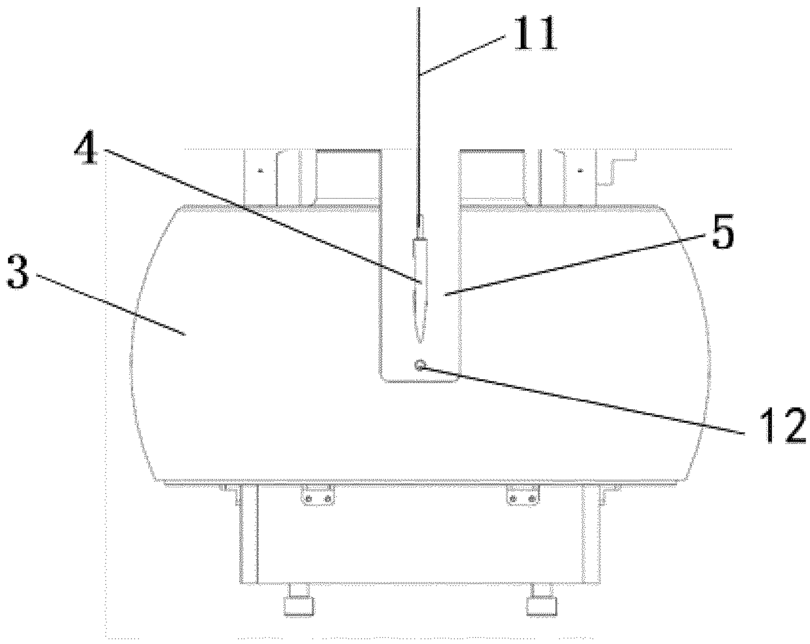

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2020/123912

A. CLASSIFICATION OF SUBJECT MATTER

B24B 49/00(2012.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B24B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNKI, CNPAT, WPI, EPODOC: 磁流变, 抛光, 弧形, 支架, 传感器, 信号, 控制, 间隙, 位移, 误差, 修订, 标定, 精度, magneto, rheological, polish+, calibrat+, gap, error, sensor, precision, arc, bracket, signal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
PX	CN 111805427 A (CHANGCHUN INSTITUTE OF OPTICS, FINE MECHANICS AND PHYSICS, CHINESE ACADEMY OF SCIENCES) 23 October 2020 (2020-10-23) claims 1-9	1-9
X	CN 109605134 A (CHANGCHUN INSTITUTE OF OPTICS, FINE MECHANICS AND PHYSICS, CHINESE ACADEMY OF SCIENCES) 12 April 2019 (2019-04-12) description, specific embodiments, and figure 1	1-5
X	CN 108255129 A (INSTITUTE OF MECHANICAL MANUFACTURING TECHNOLOGY CHINA ACADEMY OF ENGINEERING PHYSICS) 06 July 2018 (2018-07-06) embodiment 1, and figures 1 and 2	6-9
X	CN 108088388 A (INSTITUTE OF MECHANICAL MANUFACTURING TECHNOLOGY CHINA ACADEMY OF ENGINEERING PHYSICS) 29 May 2018 (2018-05-29) embodiment 1, and figures 1 and 2	6-9
A	CN 110877255 A (FACILITY DESIGN AND INSTRUMENTATION INSTITUTE, CARDC) 13 March 2020 (2020-03-13) entire document	1-9

☑ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
01 April 2021	**26 April 2021**

Name and mailing address of the ISA/CN	Authorized officer
China National Intellectual Property Administration (ISA/CN) **No. 6, Xitucheng Road, Jimenqiao, Haidian District, Beijing 100088** **China**	
Facsimile No. **(86-10)62019451**	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2020/123912

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2020/123912

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CN	110877255	A	13 March 2020		None		
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CN	103143984	A	12 June 2013	CN	103143984	B	23 December 2015

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REFERENCES CITED IN THE DESCRIPTION

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