Research on Measurement Method of Large-Bore Engine Cylinder Block Based on MMZ E Coordinate Measuring Machine

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Abstract: To address the problems of the complex structure, strict geometric tolerance requirements, and the low efficiency and insufficient accuracy of traditional manual inspection of large-bore engine cylinder blocks, this paper systematically studies a full-size measurement method for cylinder blocks based on the MMZ E bridge-type coordinate measuring machine (CMM). The structural characteristics and measurement difficulties of the cylinder block are analyzed, and the system composition of the MMZ E CMM and the CALYPSO measurement software is described. Emphasis is placed on the establishment of the measurement datum, probe configuration, measurement path planning, and geometric tolerance evaluation. Practice shows that the proposed method can complete the inspection of all key dimensions and geometric tolerances, including cylinder bore diameter and roundness, crankshaft bore coaxiality, camshaft bore parallelism, and deck flatness, in a single clamping. The measurement repeatability can reach ±0.5 μm, and the measurement efficiency is improved by more than 60% compared with the traditional method, providing a reliable technical guarantee for the precision manufacturing and quality control of large-bore engine cylinder blocks.

Keywords: Large-bore Engine; Cylinder Block; Coordinate Measuring Machine (CMM); MMZ E; Geometric Tolerance; Measurement Datum

1. Introduction

As the core power device in fields such as marine propulsion, power generation sets, and mining machinery, the performance and reliability of a large-bore engine directly depend on the manufacturing accuracy of key parts such as the cylinder block. The cylinder block carries dozens of groups of precision hole systems and planes, including cylinder bores, crankshaft bores, camshaft bores, main bearing seats, and valve guide holes, and the positional tolerances among these hole systems, such as position, coaxiality, and parallelism, are extremely strict. Traditional inspection of cylinder blocks mostly relies on manual measurement with universal gauges such as inside micrometers, dial indicators, and height gauges, which suffers from low efficiency, large human errors, and difficulty in evaluating spatial positional tolerances [1].

A coordinate measuring machine (CMM) collects three-dimensional coordinate points on the workpiece surface through a probe and calculates the dimensional, shape, and positional errors of geometric elements with software. It offers high accuracy, strong versatility, and the ability to evaluate complex geometric tolerances, and has become the mainstream means of precision inspection of engine cylinder blocks [1-2,7]. Combined with the structural characteristics and technical requirements of large-bore engine cylinder blocks, this paper systematically describes the measurement scheme, datum establishment, probe configuration, measurement path planning, and error control methods based on the MMZ E CMM, providing a reference for the three-coordinate inspection of similar large complex box-shaped parts.

2. Structure Characteristics and Measurement Difficulties of the Cylinder Block

2.1 Structural Characteristics

Large-bore engines adopt an integral cast-iron cylinder block, and the main technical parameters are listed in Table 1. The cylinder block is cast from high-strength gray cast iron with good rigidity and damping performance. Its main characteristics are: (1) large volume and heavy weight; a V-type block is more than 1.5 m long and weighs several tons; (2) complex hole

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systems, including crankshaft main bearing bores, camshaft bores, cylinder liner bores, injector holes, valve guide holes, and other dozens of groups of holes of different specifications and depths; (3) strict geometric tolerance requirements; the coaxiality of crankshaft bores, the roundness and cylindricity of cylinder bores, the flatness of the deck surface, and the parallelism and perpendicularity among hole systems all reach the micrometer level [4]; and (4) the double-row cylinders of the V-type structure are arranged at an angle of 90°, so the spatial positional relationship of the hole systems on both sides must be considered during measurement.

Table 1. Main Technical Parameters of Large-Bore Engine Cylinder Blocks

Parameter	Inline 6-cylinder	V12
Bore × stroke/mm	150 × 150	150 × 185
Total displacement/L	15.9	39.2
Block material	Gray cast iron	Gray cast iron
Liner type	Wet, replaceable	Wet, replaceable
Rated power range/kW	≈ 400	1007–1500

2.2 Measurement Difficulties

The main difficulties in measuring large-bore cylinder blocks are: (1) the contradiction between large size and high accuracy; the block is more than 1.5 m long while the geometric tolerances of the key hole systems are only at the micrometer level, requiring the CMM to maintain high accuracy over its full travel; (2) deep-hole and blind-hole measurement; the crankshaft main bearing bores form multi-bearing continuous holes, and the probe must reach deep into the bores with webs between bearings, imposing high requirements on probe length and path planning; (3) poor spatial accessibility of the V-type structure; some hole systems lie inside the included angle and require multi-directional probes or a rotary probe holder; and (4) significant temperature influence; large cast-iron parts are strongly affected by ambient temperature changes, so temperature compensation must be applied during measurement.

3. Composition of the MMZ E Coordinate Measuring System

3.1 Measuring Machine

This study uses an MMZ E bridge-type coordinate measuring machine, as shown in Figure 1. The MMZ E adopts a natural granite worktable and crossbeam, air-bearing guideways, and a grating scale with nanometer-level resolution. Combined with error compensation and an active temperature-compensation system, the maximum permissible error (MPE) can reach the micrometer level [3,9]. Its measurement travel can fully cover the measuring range of a large-bore V-type cylinder block and meet the micrometer-level geometric tolerance inspection requirements.



Figure 1. MMZ E Coordinate Measuring Machine

3.2 Probe System

The probe system directly determines measurement accuracy and efficiency: (1) a high-precision active scanning probe supports both trigger and continuous scanning modes [10] with a high sampling rate, and is especially suitable for the efficient evaluation of shape errors such as bore roundness and flatness; (2) a rotary probe holder and an automatic exchange rack realize automatic switching of the probe at multiple angles, meeting the measurement needs of the two cylinder banks and hole systems in various directions of the V-type block; and (3) a multi-specification probe rack (MSR Multi Sensor Rack, as shown in Figure 2) is used, with φ3 mm ruby probes, φ5 mm extended probes, and 90° angled probes configured according to the features; all probes are calibrated with a reference sphere before measurement.



Figure 2. Probe Rack (MSR Multi Sensor Rack)

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3.3 Measurement Software

The CALYPSO measurement software is used [8]. It supports CAD-model-based programming: the 3D model of the cylinder block can be imported and the measurement path and program are generated automatically. It has a built-in GD&T evaluation module for directly evaluating position, coaxiality, parallelism, perpendicularity, roundness, cylindricity, flatness, and other tolerances. After measurement, an inspection report is generated automatically, and the data can be connected to the PiWeb quality data platform for statistical analysis, quality traceability, and process capability monitoring.

4. Measurement Scheme Design

4.1 Establishment of the Measurement Coordinate System

The establishment of the measurement coordinate system follows the principle of unifying the measurement datum and the machining datum, using the "3-2-1" datum method: the first datum is the cylinder block bottom surface (oil pan mounting face), on which 6–9 points are collected to fit the datum plane, constraining the translation along Z and the rotations about X and Y; the second datum is the crankshaft bore axis, fitted from the first and last main bearing bores, constraining the translation along X and the rotation about Z; and the third datum is the block end face or a datum hole, constraining the translation along Y [2,5]. The coordinate system is then aligned with the design model through best-fit alignment so that it coincides with the design coordinate system, facilitating automatic programming and evaluation by selecting features on the model.

4.2 Workpiece Clamping and Positioning

Adjustable support jacks dedicated to the CMM are used, and three adjustable supports are placed and leveled at the process support points on the bottom surface of the block. The weight of the block is shared by the worktable and the support points to avoid excessive single-point loading. The clamping force is moderate and serves only for positioning, avoiding elastic deformation of the block caused by the clamping force. All measured surfaces and hole systems are kept within the reachable range of the probe, as shown in Figure 3.

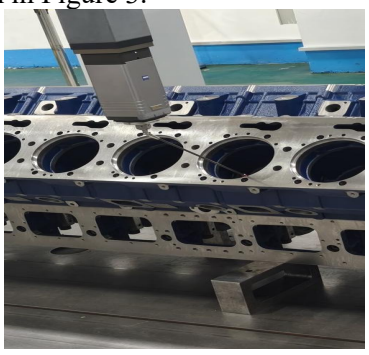

Figure 3. Measurement Site of Cylinder Block Clamping

3.3 Measurement Strategy Planning

The measurement path is planned according to the following principles: measure the datum elements first and then the measured elements so that every measurement is performed in the correct coordinate system; minimize the probe movement path to reduce idle travel time; measure the features reachable at the same probe angle together to reduce probe-exchange times; and when measuring deep holes, move quickly to the bore opening first and then slowly into the bore to avoid probe collision. The measurement strategies for typical features of the cylinder block are listed in Table 2.

Table 2. Measurement Strategies for Typical Features of the Cylinder Block

Feature	Method	Sampling points	Evaluation items
Cylinder bore	Cylinder scan	8 pts/layer × 5 layers	Diameter, roundness, cylindricity
Crankshaft main bearing bore	Circle scan	8 pts/hole × 3 layers	Diameter, coaxiality
Camshaft bore	Circle scan	8 pts/hole × 2 layers	Diameter, parallelism
Deck surface	Surface scan	10 × 8 grid	Flatness
Injector/valve guide holes	Circle measurement	6 pts/hole × 2 layers	Diameter, position

5. Implementation of Key Dimension and Geometric Tolerance Measurement

The cylinder bore is measured by cylinder scanning: data are collected at 5 layers from the top to the bottom along the bore wall, with 8 points evenly distributed at each layer, giving 40 points in total. A best-fit cylinder is fitted to output the bore diameter, roundness, cylindricity, and axis position, and the perpendicularity of the bore axis to the crankshaft bore axis is evaluated. The measurement program interface is shown in Figure 4. The crankshaft main bearing bores are measured by inserting an extended probe (about

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250–300 mm long) into each bearing for circle scanning; the axis of each bearing is fitted from 8 points at each of three height sections, and the line connecting the axes of the first and last bearings is taken as the common datum axis to evaluate the coaxiality errors of the intermediate bearings.

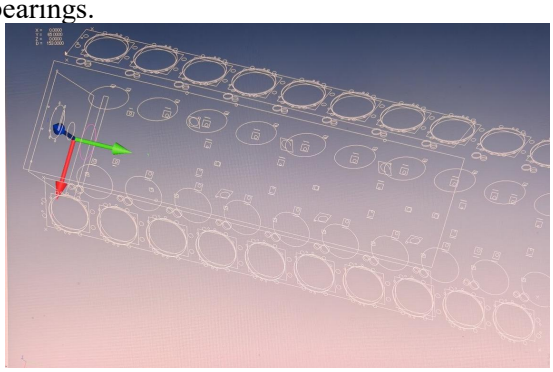

Figure 4. Measurement Program Interface of the Cylinder Block

The flatness of the deck surface is measured by scanning a 10-row × 8-column grid of points, and the flatness error is calculated by fitting the plane with the minimum-zone method. Position tolerance evaluation includes the parallelism between the camshaft bore axis and the crankshaft bore axis, the perpendicularity of each cylinder bore axis to the crankshaft bore axis, and the positions of the injector holes and valve guide holes [4]. After measurement, an inspection report is generated automatically, including nominal values, measured values, deviations, tolerance ranges, and pass/fail judgments. The data are uploaded to PiWeb to generate X-R control charts, histograms, and process capability indices (Cpk) for real-time monitoring of process stability.

6. Error Analysis and Accuracy Verification

Temperature is the most important factor affecting the measurement accuracy of large parts. The cylinder block is made of cast iron with a linear expansion coefficient of about 11.5×10^{-6}/°C. For a 1.5 m block, a temperature deviation of 1 °C produces a thermal deformation of about 17.25 μm, which is close to or even exceeds the level of some geometric tolerances. Therefore, measures such as constant-temperature measurement room (20 °C ± 1 °C), sufficient soaking of the workpiece (at least 8 h), temperature sensors for real-time compensation, and conversion of the measured dimensions to the 20 °C standard temperature according to the material expansion coefficient in the software are required. Probe-system errors mainly originate from probe calibration errors and probe bending deformation. All probe angles must be calibrated with a reference sphere before measurement; for deep holes, shorter and thicker probes should be selected as far as possible, with reduced measuring force and shape-error compensation enabled.

Accuracy verification: (1) Repeatability: measuring the same block five times under the same clamping, the repeatability of the cylinder bore diameter reaches ±0.5 μm and the flatness repeatability is not greater than 2 μm. (2) Comparison: the CMM results are compared with those of traditional methods (such as inside micrometers), and the deviations are within the measurement uncertainty [6]. (3) Periodic calibration: the indication error and probing error are calibrated regularly in accordance with ISO 10360-2 [3] to keep the CMM in a qualified accuracy state.

7. Conclusion

This paper systematically studies a full-size measurement method for large-bore engine cylinder blocks based on the MMZ E coordinate measuring machine. By establishing the measurement datum through the “3-2-1” principle to unify the measurement datum with the machining datum, configuring a high-precision scanning probe and multiple probe assemblies, and realizing fully automatic measurement of the cylinder bores, crankshaft bores, camshaft bores, and planes in a single clamping on the CALYPSO platform, the proposed method has been proven to be highly accurate (repeatability up to ±0.5 μm), efficient (an improvement of more than 60% over traditional manual inspection), and capable of traceable and statistically analyzable data management, providing reliable technical support for the precision manufacturing and quality control of large-bore engines. Future work may combine optical scanning, automatic loading/unloading, and digital twin technology to achieve fast, unmanned, and intelligent cylinder block inspection.

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