Research on straightness error detection and quality control of multi-crankshaft bores for large medium speed engine block

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Abstract. Crankshaft is the key component of internal combustion engine equipment, the machining precision of crankshaft hole has a direct impact on the performance and life of the whole engine. Aiming at the precision machining of crankshaft bore of large medium speed engine block with high precision and multiple crankshaft holes, the inspection tool and straightness measurement method of finishing process on crankshaft holes were studied. Based on the virtual manufacturing technology and the modular design concept of the checking tool and the laser detection and alignment technology, a relationship model describing the matching between the center straightness of the crankshaft hole and the crankshaft deflection is established. A single crankshaft hole shape and position tolerance measurement and multi-crankshaft hole are designed. The special measuring tool for measuring center deflection is verified by experiment to find the compensation law for the deflection of linearity evolution, and should be used in the process of finishing with crankshaft hole. The results of many cutting experiments and laser measurements show that the tool can effectively measure the size deviation and deflection of crankshaft holes, and form a quality control method for crankshaft holes finishing. This study aims to provide a set of measurement methods for crankshaft holes straightness error of large internal combustion engine block.

1. Introduction
Internal combustion engine is a kind of thermodynamic engine which burns the fuel in the engine and converts the heat energy from the fuel into power directly. Generally speaking, it mainly includes reciprocating piston internal combustion engine, rotating piston engine and free piston engine.

Large internal combustion engines are widely used in all kinds of transport vehicles (automobiles, tractors, diesel locomotives, etc.), mining, construction and engineering machinery. The precision grade of crankshaft holes, camshaft holes, cylinder holes and intermediate gear holes in the key parts of the engine block is very difficult to finish machining. Tool and product collisions are easy to occur when machining on the universal large gantry milling machine [1]. As the power output part of diesel engine, crankshaft hole assembly accuracy directly affects the efficiency of the product, and the machining accuracy of multiple crankshaft holes on the same block is the main influence factor of assembly accuracy. Too large or too small crankshaft holes will have a great impact on the service life and performance of the body. Therefore, the necessary prerequisite for accurate machining of multi-crankshaft hole straightness of large block is to detect the straightness in the machining process and select the corresponding compensation according to the measurement results, so as to adjust the follow-up processing [2], so that the measurement and compensation of machining process is particularly important for the precision machining process system of large-sized and high-precision
The design of measuring tools for machining process around the effectiveness and efficiency has been widely concerned by engineers and technicians.

Zhang Kan developed a special combined boring machine for machining the spindle hole of locomotive engine block, analyzed and determined the technological requirements for repairing the spindle hole of the block and the deflection of the boring bar under two different conditions, designed and manufactured a special combined boring machine for repairing the spindle hole and the corresponding fixture [3]. At present, many manufacturers in China adopt the two-axis plating machine to roughen the camshaft hole of 6-cylinder internal combustion engine block. Due to the improper selection of machining amount, it is easy to produce the camshaft hole which can not completely eliminate the defects caused by rough machining after semi-finishing [4]. Professor Wu Xianming of Wisconsin New University of America is the first one in grinding process. The roundness error of workpiece was compensated successfully by DDS method [5]. The roundness of workpiece taper was reduced from 074 micron to 0.375 micron by modeling and compensating the radial error of spindle of external cylindrical grinder in Wisconsin University [6]. The roundness error of workpiece taper was measured by Kalman filter method in literature [7], and the accuracy of axial workpiece in external cylindrical grinding was effectively improved. But this kind of inspection tool can only be used for final inspection of products, and can not be used as a process inspection tool. In addition, the stability of machine tools, process parameters such as temperature, etc., will also have an impact on the accuracy [8]. Therefore, ensuring that every factor changes in its reasonable range is the key to ensure the quality of crankshaft bore boring.

Based on the above situation, taking the L-type large marine engine block of a certain company as the research object, based on the virtual manufacturing technology, drawing on the modular design concept of the checking tool and the laser detection and alignment technology, the relationship model describing the matching between the center straightness of the crankshaft hole and the crankshaft deflection is established, and the shape and position tolerance of the single crankshaft hole is designed. The special measuring tool for measuring the center deflection of multi-crankshaft hole is verified by experiment to find the compensation law for the deflection of linearity evolution, and should be used in the finishing process with crankshaft hole.

2. Machining accuracy of crankshaft hole for a large engine block
Large internal combustion engine has large structure size, high machining and assembling accuracy requirements, a wide range of processing parts, more process involved, special detection methods, so the requirements of equipment, technology, precision detection and other comprehensive conditions are very harsh. Fig. 1 is the design feature of multiple crank holes on a large internal combustion engine block.

Figure 1. Design model of a large internal combustion engine block.

At present, the processing technology of large internal combustion engines is at a bottleneck stage in China. For one thing, the old-fashioned modular machine tools are used in machining methods, so their universality is poor; for another thing, the precision measuring tools are mostly conventional types, which can not achieve efficient and fast measurement, resulting in high rejection rate in processing foreign high-precision internal combustion engine products. With the development of
internal combustion engine units towards super-large, high efficiency and complexity, the detection methods of machining errors and the design of special inspection tools are still the key research fields at home and abroad. Especially for a large internal combustion engine block shown in Fig. 1, the long-distance straightness inspection with multi-crankshaft holes and other characteristics is still the focus of attention, and the measurement is the key problem that needs to be solved urgently.

The design structure for crankshaft hole of the large internal combustion engine block is shown in Fig. 1. The total length of the crankshaft hole is 5550 mm. The diameter of the crankshaft hole is ø400 mm, the thickness is 100 mm, the distance between the two crankshaft holes is 500 mm, and the difference between the two crankshaft holes is 0.03 mm in the height direction. The deflection curve shows that the roughness of the inner hole is Ra1.6, the specific design parameters are shown in Table 1. It can be seen that the straightness tolerance is very strict, coupled with its high roughness requirements, if there is a small amount of deviation in the process, will lead to processing scrap.

| Margin               | mm |
|----------------------|----|
| Crankshaft hole diameter | ø400 |
| Crankshaft hole thickness     | 100 |
| Center distance            | 500 |
| Height difference          | 0.03 |

According to the different models of the whole machine, there are 10 different sizes and specifications of the body structure, but the crankshaft hole center straightness tolerance and crankshaft hole size and tolerance are the same. Therefore, the design of a fixture can be applied to the measurement of the center straightness of the crankshaft holes of the various specifications.

3. Fixture design
In the national standard, the coaxiality tolerance of the axis is defined as "the tolerance zone is the area within a cylindrical surface with a diameter of and the axis of the cylindrical surface is coaxial with the reference axis". It has the following three control elements: a) the establishment of the reference axis; b) the establishment of the axis of the object under test; c) considering the actual work or assembly requirements for flexibility.

The function of the internal combustion engine block is clear and relatively stable. From the processing technology, the large Longmen milling machine can be processed in two states. Although the number of cylinder holes is different in different series, the spacing of all cylinder holes in the middle is the same, and the structural dimensions on both sides have the same distribution characteristics with the cylinder hole surface. Therefore, it is more appropriate to adopt structural modularization to design the processing tooling in two conditions. According to the above modular division of the block structure, the corresponding modular assembly structure is designed on the premise that the large gantry milling machine is selected as the processing equipment, as shown in Figure 2.
Figure 2. Special fixture of coaxiality for crankshaft bore.

a) The fixed datum tool

b) The movable measuring tool

c) The laser emission and detection device
The modular special measuring tool includes three sub-tools, which are fixed datum tool (the first crankshaft hole installed at any end of the measurement is regarded as the measurement datum), movable measuring tool (installed in the crankshaft hole to be detected) and laser measuring tool. The tool can realize the functions of unifying the locating datum of each mounting, satisfying the processing of different specifications of the engine block with the same locating datum, reducing the time of repeated installation and disassembly, and completing the overall processing time of the under-line mounting card. It provides a quick tool for the pipeline processing of the engine block.

4. Testing method for finishing process

In order to ensure the accuracy of measurement, a rectangular groove with a width of 0.3 mm is opened at the same position of the center hole of the benchmark and movable tooling, and a standard thickness measuring block is installed on the same side of the rectangular groove. The standard thickness of the measuring block is 0.2 mm.

The measuring principle adopted in this device is to convert the measurement of coaxiality of two holes into the offset measurement of four points on the upper and lower sides of the center hole of the two tooling, and then convert it into coaxiality. The accuracy of crankshaft hole coaxiality is judged by measuring offset. The precondition of measuring the special measuring tool is to ensure that the crankshaft hole circle runout processing conforms to the design scope. The specific measuring steps are as follows:

4.1 Preparation before measurement

Cleaning the of the tools surface to prevent foreign bodies from entering the inner surface of the tooling and crankshaft hole, otherwise the tooling can not be closely assembled with the parts under test, thus affecting the accuracy of the measurement data.

4.2 Loading card

Firstly, the benchmark fixture is installed in the first crankshaft hole on the left side as shown in Fig. 1, and the gap between the tool and the outer surface of the measured shaft is detected by using a 0.01 mm thickness stopper. If the stopper can be accessed locally and the symmetrical position is found, the fixture and the measured shaft are incorrectly clamped, and the benchmark fixture needs to be tapped straight. If there is only a gap on one side, the plug can enter, which means that the machining circle runout error of the inner surface of the crankshaft hole is large, and the value of the circle runout can be determined by selecting the gradually increasing thickness of the plug in turn. If the 0.01 mm thick plug can not enter any contact position between the tool and the measured shaft, the clamping is completed.

Secondly, the movable tooling is installed in the second position of the crankshaft hole, and the specific installation method and the method of checking the installation are the same as the above method.

4.3 The coaxiality Measurement

The laser measuring unit is placed in the fixed position of the benchmark fixture, and the laser beam is opened. The data displayed on the screen of the movable fixture is read and recorded, that is, the deviation value of the center point of the first crankshaft hole and the second crankshaft hole, which reflects the specific deviation of the center of the two measuring crankshaft holes in the longitudinal and horizontal directions respectively.

Remove the movable tooling from the second crankshaft hole, place it with the next crankshaft hole at one time, read the measurement data displayed on the display screen and record it, and so on until the deviation between all crankshaft holes and the first reference hole is completed.

Because the design requirements only care about the crankshaft hole center in the longitudinal direction of the deviation, so the recorded data of each measurement position is compared and processed, converted the deviation between the adjacent two crankshaft holes, and compared with the
design accuracy to determine whether to meet the requirements of processing accuracy, so as to complete the measurement.

5. Conclusion
In this paper, a large internal combustion engine block is taken as the research object, and its finishing quality is measured by designing a special measuring tool for crankshaft hole. It can be seen that the simulation of product machining process based on virtual manufacturing technology can accurately evaluate the machining difficulties, specify effective measures and optimize the machining process, and solve the technical difficulties of machining the block. Based on the virtual manufacturing technology and the modular design concept of the measuring tool and the laser detection and alignment technology, a special measuring tool is designed for measuring the shape and position tolerance of single crankshaft hole and the center deflection of multi-crankshaft hole. The fixture can effectively measure the size deviation and deflection value of the crankshaft hole.

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