Research and Analysis Based on Three-dimensional Precision Inspection Process Planning Technology

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Abstract. Three-dimensional precision inspection has the characteristics of digitization, completeness, and timeliness. The manufacturing industry needs to research and improve the existing inspection process planning technology. Carried out research on the key technology of three-dimensional inspection process planning, including inspection information extraction, inspection point planning, path planning, etc., compared and analyzed the offline inspection technology represented by the coordinate measuring machine and the online inspection technology represented by the machining center. Studied and analyzed the system architecture, main functional modules of process planning software tools for these two types of inspections; finally, it looks forward to the future development trend.

1. Introduction

In the past, most of the processing in the manufacturing industry used a combination of common machine tools and CNC (Computer numerical control) machine tools, and the automation of the production process was low. The inspection process planning problems were often focused on selecting measurement instruments and accuracy and writing measurement reports. With the rapid development of precision CNC machining technology and the application of design technology based on MBD (Model-Based Definition) model-driven design process technology, three-dimensional precision inspection (hereinafter referred to as 3D inspection) has become one of the important directions of precision mechanical parts quality inspection[1], the 3D inspection process planning technology refers to the overall planning of the parts to be inspected directly on the 3D model. The key technologies include defining inspection elements, automatic generation of inspection sequences, paths, methods, and automated analysis of inspection data. This is quite different from traditional inspection process planning.

At present, a large number of scholars have also carried out fruitful research on this technology. For example, Zeng et al.[2] improved the measurement efficiency and intelligence level of the CMM (Coordinate Measuring Machine) for complex shapes in aircraft structural parts through feature recognition, measurement point distribution, and measurement direction optimization; Qu et al.[3] take the MBD detection model as the carrier, extracted inspection information, linked the three-coordinate detection links, designed a three-coordinate detection process system based on MBD; Han et al.[4] proposed a path optimization method with time as the optimization goal based on the ant colony algorithm. Phan et al.[5] proposed a scanning path planning method for the online measurement of five-axis machine tools. Wang et al.[6] integrated the original detection technology with CAD software and designed the online detection system to set the relevant functions of each module.

The current 3D inspection process planning technical problems are mainly concentrated in offline
inspection (That is disassembled from the machining station of the machine tool and then inspected on an independent inspection station or inspection equipment) and online inspection (Do not disassemble after the machining of the machine tool, directly use the machine tool motion mechanism for inspection) [7]. In order to solve the problems existing in the traditional inspection process and its implementation process, 3D inspection process planning technology and methods are applied to improve the accuracy, efficiency, and real-time performance of parts inspection. The following will mainly study and analyze the key technology of 3D inspection process planning, the planning software tool system architecture and functional modules to carry out research, and finally discuss the future development trend of the technology.

2. Key technology of 3D inspection process planning

| Detection method | Advantages | Disadvantages |
|------------------|------------|---------------|
| **Off-line inspection** | (1) The detection accuracy is high, and the measurement of complex curved surfaces is convenient and fast; (2) Better measurement system error compensation effect. | (1) There is a positioning error in the secondary clamping, and there is a waste of time when handling the work piece; (2) Measuring system is generally expensive. |
| **On-line inspection** | (1) The detection efficiency is high, and the operation requirements are not high; (2) Avoid the errors caused by repeated disassembly and assembly. | (1) The accuracy of the machine tool will affect the measurement accuracy, and there are many error factors; (2) The measurement accuracy of complex curved surface is not high, error compensation is difficult. |

3D inspection is often combined with other technologies to improve measurement efficiency and accuracy, such as inspection process planning techniques, point cloud stitching, image processing, etc. The technical problems of 3D inspection process planning were mainly focused on offline inspection and CNC online inspection, both of which differ in their application methods and technical characteristics. A comparison of the advantages and disadvantages of offline inspection and online inspection of CNC machining is shown in table 1.

2.1. Offline inspection

2.1.1. Selection of offline testing equipment. As a representative and commonly used offline testing equipment and method, CMM has the technical advantages of high precision and good flexibility and has gradually become one of the main methods of product testing and quality control in manufacturing enterprises. The CMM measurement system has several primary structural forms [8], as shown in figure 1, which can be selected according to different application scenarios. In the actual offline detection process, suitable measurement sensors need to be chosen according to the measurement object, demand, and scene to improve the accuracy of three-dimensional detection.

![CMM main structure classification](image)

**Figure 1. CMM main structure classification**

2.1.2. Detection information extraction. The traditional three-coordinate measurement technology mainly transmits detection information through engineering semantics based on two-dimensional engineering drawings. The main types of detection information are shown in figure 2. In order to
improve the transmission efficiency and standardization of detection information, the detection information has been upgraded from two-dimensional expression to three-dimensional expression. The MBD and the "model-driven" product development models have become a new trend[1,4].

![Diagram of main detection information](image)

**Figure 2. Main detection information**

2.1.2.1. **MBD technology.** MBD technology uses a three-dimensional solid model as the only carrier of design and manufacturing information. Through the relevance of its physical model and annotation information, the inspection information is divided into tolerance information and associated geometric information, Three levels of additional geometric information[9], as shown in table 2.

| Information classification | Detection information | reason |
|----------------------------|-----------------------|--------|
| level one                  | Dimension information, shape and position tolerance information | The highest inspection priority, which can express the main inspection requirements of the part |
| level second               | Geometric information | Express the parameters, type and location of the test object |
| level third                | Additional non-geometric information | Supplement information for testing planning |

The MBD-based inspection process model can automatically obtain the MBD data set through three-dimensional inspection technology. Inspection Information (defined key features and dimensions)[10], generate a file format (such as DMIS file format) that can be directly read and executed by the inspection equipment, digital measurement equipment executes the measurement program, and directly evaluates the measurement program through software algorithms, and finally obtains a measurement report. The three-dimensional inspection process The model information organization structure is shown in figure 3[11].
Three-dimensional inspection process model

- 3D part model
  - Non-geometric properties
  - Property notes
  - Testing requirements, raw materials, etc.
- 3D process model
  - Geometric attributes
  - Label
  - Heat treatment requirements, precision requirements, etc.

Figure 3. Information organization structure of inspection process model

2.1.2.2. PMI information extraction. The screening of MBD information and detection information extraction is mainly obtained through PMI (Product Manufacturing Information). The node objects marked by PMI are geometric objects in the solid model, and the information obtained by marking the associated objects is the geometric detection information. With the MBD model as input, UG secondary development technology can extract part inspection in formation parameters by reading the PMI information list formulated, defining the names of point, line, and area elements in the model, and using human-computer interaction. In this way, the PMI information of the three-dimensional model can be quickly marked [12]. Offline inspection can effectively extract inspection information according to the MBD model to achieve more optimized inspection process planning.

2.1.3. CMM Inspection path planning. The object of CMM inspection path planning is the probe, and the probe's motion trajectory (translation and rotation) must be evaluated. Therefore, it is necessary to comprehensively consider the time consumption of probe change and the optimal sequence of detection features to achieve path optimization.

(a) Detection feature

(b) Detection feature group

Figure 4. Return path

The traditional shortest path method with the detection feature as the detection unit requires that the measurement of the following detection feature can only be performed after all the detection points on a detection feature are measured, as shown in figure 4(a). To solve the above problems, to achieve the optimization goal of the least probe change and the shortest path, Wang et al.[13] proposed the most straightforward time method with the detection feature group as the detection unit. It can achieve mixed measurement of detection points with different features, as shown in figure 4(b) (divide the parts on the reference surface into three groups: cylinder, cone, and groove). This grouping can avoid generating the return path, which improves detection efficiency and safety.
2.2. CNC machining online inspection

2.2.1. Online detection application scenario selection. The three-dimensional inspection of precision parts needs to improve efficiency while ensuring accuracy. Among them, the online inspection of CNC machining has the characteristics of automation and real-time. The inspection results directly guide the processing, making up for the lack of offline inspection to a certain extent[14]. The composition of the CNC online measurement system is shown in figure 5.

![Composition of CNC online measurement system](image)

**Figure 5. Composition of CNC online measurement system**

The main classification of the CNC online inspection probe is shown in figure 6. As shown in, proper planning of probe selection according to different detection scenarios is a prerequisite for ensuring detection quality. The most commonly used is contact probes [15].

![Main classification of CNC online inspection probe](image)

**Figure 6. The main classification of CNC online inspection probe**

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2.2.2. Distribution of detection points. The online inspection process is completed by touching the probe with all the inspection points. The number of inspection points on the surface of the test piece and their distribution needs to be determined in advance. At present, measurement point generation methods mainly include the isoparametric sampling method, simple random method, Hammersley sequence method, etc.[16]. With the increase of surface inspection objects in parts, three-dimensional inspection should be based on the processing function, tolerance range, curvature, and the number and distribution of measuring points are planned for machining errors[17].

2.2.3. Inspection path planning. Online inspection path planning determines the path optimization function based on the total path length, measurement time, etc. It uses the optimal algorithm to solve the problem to obtain the optimal path and ensure that the probe travels without collision. The part process model in the inspection process is often. With the dynamic changes of the processing process, the inspection process is complicated. Therefore, Ding et al. proposed an online inspection path planning method based on the inspection state model ISModel (Inspection State) to solve this
difficulty. The inspection path is regarded as typical hierarchical planning. The questions are divided into three levels, as shown in Table 3.

| Inspection planning level | Planning content |
|---------------------------|------------------|
| Inspection operation level planning | Through feature recognition and process requirements, the process of part online inspection is determined, and the corresponding inspection feature information and processing status information during each inspection operation[18]. |
| Detection feature level planning | First determine the feature detection sequence, test all features of the detection operation level in sequence, and then plan the detection path between features according to the detection sequence with the shortest path sum. |
| Test your own level planning | Retrieve the information of the feature in ISModel, consider the back distance of the probe, and the margin of geometric surface, and plan the path of the detection point in the feature. |

3. Three-dimensional inspection planning software system

3.1. Detection system composition and software architecture

3.1.1. Three-coordinate detection system. With the development and improvement of CAD technology and DMIS standards, the development of the CMM-oriented CAIP system has realized the offline intelligent automatic generation of CAD-based inspection planning, such as the CMM inspection planning system based on 3D CAD typical structure, As shown in Figure 7. Yu[19] used the functions and operations in the NX/Inspection module for secondary development and designed an MBD-based intelligent three-coordinate inspection process planning system. The overall structure is shown in Figure 8. Offline testing is through offline planning and simulation, from code generation to the final output program [20,21]. Still, the CNC system is expensive, the processing is the main task, and testing is supplemented. Online planning often imports the existing program (the first piece must be in Machine programming).

![Figure 7. CAD-based CMM inspection planning system[22]](image-url)
3.1.2. **Online inspection system.** In order to realize the function of online detection, the online detection system should include the following modules, as shown in figure 9. Among them, measurement path generation and simulation module, measurement error module, communication module, etc., are the core modules [23].

Li[24] developed an on-machine inspection planning system based on procedures and characteristics. The operation and functions of the interface and functional layers are realized through the related supporting services and data of the service and the data layers. At the same time, the system will update and display the associated data returned to the interface. The modules provide human-computer interaction functions to realize the operation and data of the system. Control, as shown in figure 10.
3.2. Three-dimensional inspection process planning module
The functions of process planning related modules in the 3D inspection system can realize the application of inspection process planning techniques, such as probe planning, number and location of measuring points, and inspection path planning. In the MBD-based intelligent three-coordinate inspection process planning system, the inspection process planning The intelligent planning module mainly includes the following parts, as shown in table 4. For online inspection systems, take Li’s on-machine inspection planning system based on procedures and features as an example. The functions of the inspection planning module are shown in table 5 below:

| Intelligent planning module | Function |
|-----------------------------|----------|
| Probe planning               | Properly plan the probe according to the testing needs |
| Number of measuring points   | The number of measuring points and the distribution plan are dynamically modified during the intelligent sampling strategy planning[16]. |
| Inspection path planning     | The path planning efficiency is improved by phased detection path planning. After the path planning is completed, a virtual detection simulation is performed to locally adjust the way [7]. |

| Module                  | Function |
|-------------------------|----------|
| Interface layer         | It mainly provides users with a platform for interacting with the system, including the selection of various functions such as process inspection planning, measurement point planning, path planning, etc., for users Check and perform corresponding operations. |
| Functional layer        | It mainly includes the reading of CAD model files, the display of CAD graphics, the operation of views, the planning of measuring point paths, and the display of planning results. |
| Service layer           | As the core module of the entire system, it provides related services for the realization of various functions: CAD services; planning services; computing service; data loading and storage services[24,25]. |
| Data layer              | Mainly store data related to on-machine inspection planning. At the same time, manual input data can be obtained through human-computer interaction[7]. |
4. Conclusion
This paper compared and analyzed the key technologies of offline inspection and online inspection of CNC machining regarding process planning, studied the three-dimensional inspection software system architecture, main functional modules, and applications corresponding to these two types of inspection systems. The future research direction of 3D precision inspection process planning technology will focus on the following aspects: (1) Based on the MBD model drive, the automation and accuracy of the extraction and classification of product inspection information through the inspection process planning improved to meet corporate information. The requirements of quality data digitization, completeness, and timeliness of the quality data; (2) Comprehensive analysis of the influencing factors of the inspection path, creating a reasonable optimization problem model, and seeking intelligent algorithms for path optimization to improve the accuracy and efficiency of 3D inspection; (3) Consider the adaptability of 3D inspection process planning technology to different products, and improve the 3D inspection ability of measurement software.

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