

Research and Application of Automatic Production Technology of Drill Pipe Joint for Coal Mine

Zhifeng Wu*

Xi'an Reserch Insititute Co.Ltd,China Coal Technology and Rngineering Group Crop, Xi'an, China

*wuzhifeng@cctegxian.com

Abstract

The current demand for drill pipe joints in the coal mining industry continues to rise, and has put forward higher requirements on its quality and production efficiency. Traditional manual and semi-automated production models are no longer able to meet the development needs of the industry. With the increasing improvement of automation technology, especially the technology combining industrial robots and CNC machine tools has been applied and widely recognized in many related fields. The article designs the overall plan for drill pipe joint workstations for coal mine tunnels. Through the research of processing equipment, automated loading and unloading systems and automatic detection technology, an automated and intelligent production line is designed and established. The automated workstation can realize a batch fully automated process from loading and unloading, processing and optical inspection. The application of workstations greatly reduces workers' labor intensity, improves production efficiency, product quality level, and production automation and intelligence level.

Keywords

Coal Mine; Joint of Drill Pipe; Automatic Processing; Optical Inspection; Research Application.

1. Introduction

In the equipment manufacturing industry at home and abroad, robot technology has been widely used in various machining occasions, and its high speed, high precision and pollution-free characteristics have been recognized by today's society. The automobile industry, engineering machinery and other industries have already equipped industrial robots with supporting automated production lines to meet the development needs of modern enterprises and improve product quality and production efficiency [1]. At present, the application of robots is mainly based on the assembly line operation environment. With the transformation and upgrading of my country's equipment manufacturing industry, under the dual role of market demand and technological progress, robots have developed into an important part of flexible manufacturing systems (FMS) and flexible manufacturing units (FMC). The robot and machine tool equipment are combined to form a flexible manufacturing unit or flexible manufacturing system. The structure is compact, which can save a large amount of workpiece conveying devices, reduce operators, and ensure product consistency. Flexible manufacturing systems composed of robots and CNC machine tools have gradually become a new trend and development need [2,3]. The geological drill rod for coal mines is manufactured by friction welding of the intermediate rod body and joints, where the joint thread part is a key process in product manufacturing, which is completed on a CNC lathe. Each joint processing must go through the loading, clamping, turning and unloading.

Under the traditional single-person production model, workers must put up and down the workpieces and inspect them hundreds of times a day. The labor intensity is high and the degree of automation is low. Product inspection generally uses traditional circumvention inspection, which is prone to quality problems due to the instability of manual operation. The use of industrial robots and automated detection technology can eliminate manual uncertainties, ensure smooth loading and unloading of machine tools and stability of product quality, reduce product failure rate, and improve the automation and intelligence level of overall processing [4,5]. In view of this, this paper research is based on the actual pain points of thread processing of geological drill pipe joints for coal mines. It aims to deeply integrate industrial robot technology with automated inspection technology to build an automated processing system suitable for this process, so as to realize the full process automation of drill pipe joints from loading and unloading, processing to quality inspection, and thus solve problems such as high labor intensity, low degree of automation and insufficient quality stability. To achieve this goal, the research will analyze the process requirements and existing process bottlenecks of drill pipe joint thread processing, carry out robot workstation layout design, automated inspection solution integration and control system development, so as to realize the coordinated operation of robots, CNC machine tools and inspection equipment. It is expected that through this study, the automated system built can effectively reduce workers' labor intensity, significantly improve the level of automation and intelligence of the processing process, and stabilize product quality and reduce the unqualification rate through the introduction of automated testing. This achievement can not only provide solid technical support for the efficient and high-quality production of geological drill rods for coal mines, but also has important practical significance for improving the manufacturing level of this type of product, but also provides a feasible path for the upgrade of flexible automation processing and upgrading of similar parts in the equipment manufacturing industry. It follows the development trend of flexible manufacturing systems and has a positive and far-reaching role in promoting the technological progress of the industry.

2. Design of the Automated Production Line

After selecting the equipment, the overall layout was designed. Considering that drill pipe joints of different specifications share similar external shapes and thread machining methods, with relatively fixed workpiece clamping positions and robotic motion trajectories, the workstation integrates gantry robots with four CNC machine tools. The gantry structure consists of columns, crossbeams, X-axis/Z-axis motion mechanisms, and robotic grippers. Supported by three parallel columns, two crossbeams form a rigid frame to bear the weight of the motion systems, which adopt servo motors and rack-and-pinion drives for their simplicity and high stability [6].

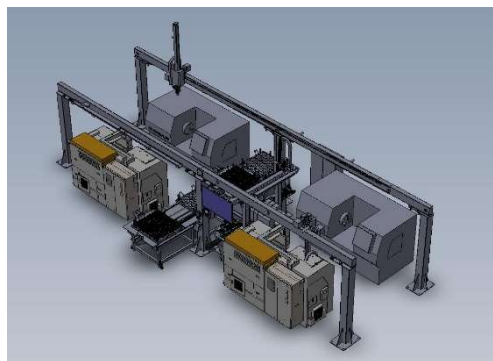


Figure 1. Overall scheme design drawing

Two multifunctional material bins supply workpieces to the respective gantry systems. Each bin comprises a base, a mobile platform, and pallets. The mobile platform, driven by a servo motor via a

belt and ball screw, moves along the Y-axis on the base, forming the Y-axis motion for the gantry system. Quick-release fixtures enable rapid pallet replacement, minimizing auxiliary time.

Considering the installation dimensions of CNC lathes and the travel speed of gantry robots, a single gantry system was configured to handle loading/unloading for two lathes. This compact layout maximizes vertical space utilization, deviating from conventional planar arrangements [7]. The overall configuration is illustrated in Figure 1.

A dual-chuck fixture (as shown in Figure 2) was designed according to the structure of the drill pipe joint. It can accommodate the clamping of joint products of different specifications and realize the simultaneous picking of finished products and replacement of blanks in one operation, which is convenient and efficient [8,9].

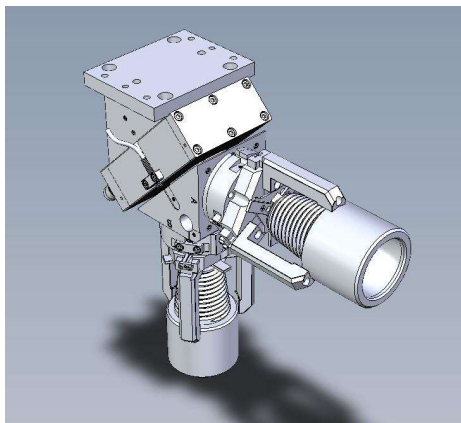


Figure 2. Double collet structure fixture

An optical inspection system is adopted for quality testing of finished products, with the inspection device located at the center of the workstation. A small gantry device is used to transport workpieces to the inspection station. A cleaning station is designed to remove residual coolant, iron chips, and other debris from the thread surface, ensuring that inspection results are not affected. Workpieces are inspected at the inspection station, and unqualified products are conveyed out through a dedicated rejection station without being returned to the material tray.

3. Design of the Control System

The entire workstation is controlled by a PLC (Programmable Logic Controller), which enables signal intercommunication and coordinated operation between the main gantry system and CNC machine tools. During processing, the inspection station collaborates with the auxiliary gantry system to complete the entire workflow of loading, inspecting, and unloading workpieces. An automated control program was developed based on the workstation's process flow and cycle time to ensure efficient operation and seamless integration of all system actuators [10,11].

The PLC programming process involves:

- a, Analyzing control requirements based on the production process
- b, Determining and allocating I/O points for the PLC
- c, Designing the I/O connection diagram
- d, Creating a system control flowchart to illustrate operational sequences and conditions
- e, Developing the PLC program

The PLC control program manages the optical inspection gantry system, optical inspection device operations, and data transmission. It consists of a main program and several subroutines, including material handling cycles, fault alarms, robot loading/unloading communication, equipment reset,

manual control modules, cycle process control, and automatic servo control. The program flowchart of the PLC control system is shown in Figure 3.

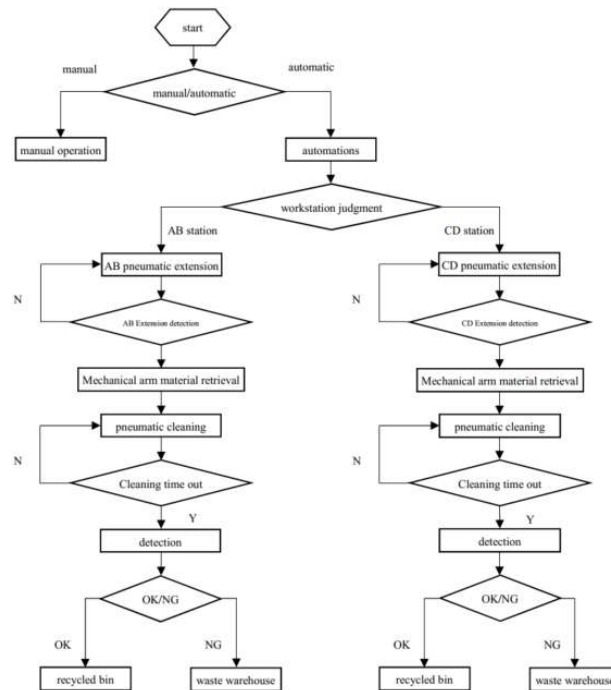


Figure 3. Control system flow chart

Design of the control circuit: According to the overall scheme, the control circuit of the automatic workstation for drill pipe joint processing was designed to achieve various expected functions.

4. Development of Optical Detection System

The methods for thread detection mainly include contact and non-contact approaches. Contact detection methods primarily encompass comprehensive measurement (e.g., gauge measurement) and single-item measurement (e.g., three-wire measurement). Non-contact methods mainly rely on thread image information, such as tool microscopy and machine vision detection. With the advancement of thread detection technology, the degree of automation has increased significantly. However, traditional contact-based methods for external threads suffer from issues like rapid wear of measuring tools and low efficiency, making them unsuitable for high-volume, online inspection requirements. To meet the demands of automated production, research and experiments were conducted on the automated detection of large-diameter tapered threads in drill pipe joints.

After comparing several existing measurement methods, it was found that the probe contact method, despite its high precision, is inefficient (the threading process for a single drill pipe joint takes less than two minutes), rendering it impractical for mass production. Therefore, an automatic thread inspection machine and optical measurement methods suitable for batch industrial production were investigated, and a test bench was built for experimentation [12,13].

The automatic thread inspection machine integrates a servo motor and a thread go/no-go gauge. It uses a flexible connection mechanism to eliminate the reverse impact on the servo motor and detection system after thread tightening, effectively verifying the thread connection status. By installing auxiliary measurement devices to detect the dimensions between the tightened thread and the ring gauge, the machine can determine whether the thread processing dimensions are qualified. A test bench was constructed (Figure 4) to detect the state of the thread pitch diameter during ring gauge inspection and provide inspection results. Through software development, this method enables batch

production inspection of drill pipe joints. Experimental results validated the feasibility of this approach.



Figure 4. an experimental platform built by using thread detector

Industrial optical measurement technologies are primarily integrated systems. However, the structural dimensions of drill pipe joints and the requirements for batch inspection pose challenges for existing integrated equipment. Therefore, an optical detection test bench was developed, consisting of the following main components: an industrial camera, planar light source, high-magnification telecentric lens, clamping fixture, rotary servo motor, industrial computer, and grayscale algorithm software written in C++. The industrial camera captures images of the external thread from various angles, while the planar light source illuminates the target surface. The telecentric lens ensures accurate imaging, and the clamping fixture positions the joint securely. The servo motor rotates the joint at a controlled speed, enabling comprehensive scanning. The industrial computer runs the grayscale algorithm software, which analyzes the captured images to compute critical dimensions [14]. Figure 5 illustrates the thread profile imaging of a drill pipe joint.

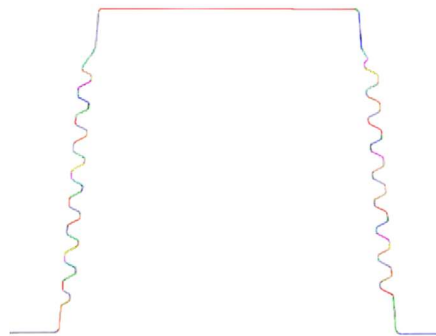


Figure 5. Drill pipe joint thread contour imaging

Through comparative analysis, both automated detection devices and optical inspection methods can meet the workstation's requirements for automated drill pipe joint inspection. However, automated thread detection devices necessitate dedicated thread ring gauges for each product type, requiring regular calibration and tool changes. Each inspection cycle involves three sequential actions: thread tightening, measurement, and loosening. Adjustments to the detection device are mandatory when switching between workpiece specifications, limiting the system's flexibility and complicating simultaneous production of diverse components. Conversely, optical detection technology offers superior adaptability through software-driven algorithms. A single optical system can accommodate multiple workpiece specifications, eliminating the need for hardware reconfiguration. Based on these advantages, optical detection was selected for the automated inspection of drill pipe joints.

The optical inspection system employs high-resolution CCD cameras to capture precise planar projections of the drill pipe joint threads. Unlike standard threads, large-pitch tapered threads exhibit distinct characteristics:

- a, Linear variation in thread profile dimensions
- b, Large helix angles
- c, Substantial planar projection areas that vary functionally with thread length and taper
- d, Complex geometries with adjacent thread roots and crest tops connected by arc-line-arc segments

Proprietary algorithms were developed to reconstruct accurate thread geometries from optical projections, enabling non-contact, online, high-speed, and high-precision inspection of large-pitch tapered external threads.

The detection system comprises:

- a, CCD cameras
- b, Industrial control computer (IPC)
- c, IO cards
- d, Input/output interface boards
- e, LCD display

Upon receiving a trigger signal from the PLC, the CCD cameras capture images, which are transmitted to the IPC via the interface boards. The optical inspection software processes these images, calculates critical thread parameters (e.g., pitch, thread thickness, thread height, total thread height, taper, crest diameter, flank length, root diameter), and transmits pass/fail results back to the PLC control system [15].

The optical system extracts feature points from the workpiece images to compute key thread parameters.

- a, Pitch: Distance between adjacent thread crests
- b, Thread Thickness: Width of the thread at the pitch diameter
- c, Thread Height: Vertical distance from crest to root
- d, Total Thread Height: Cumulative height of all threads
- e, Taper: Rate of diameter change along the thread axis
- f, Crest Diameter: Outer diameter at the thread crests
- g, Flank Length: Length of the thread flank
- h, Root Diameter: Inner diameter at the thread roots

This approach ensures comprehensive and precise inspection of drill pipe joint threads, meeting the stringent requirements of industrial automation.

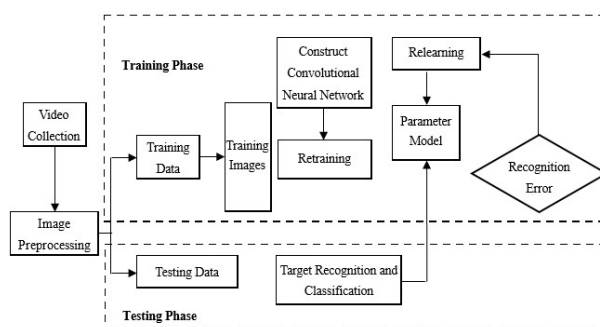


Figure 6. Detect deep learning process

After calculating the thread characteristic parameters, it is necessary to determine whether the thread is qualified. Therefore, the critical ranges for each parameter need to be set. Deep learning was employed to determine the ranges of thread characteristic parameters for various specifications [16] (Figure 6).

In practical application of the system, the feeding manipulator places the joint vertically into the rotatable fixture, which clamps the joint vertically. The servo motor controls the rotating fixture to rotate clockwise at a certain speed. The high-definition CCD camera takes a photo every 0.4 seconds according to the set shooting time and uploads the photos to the industrial computer. The grayscale algorithm software in the computer processes and calculates the pictures, automatically converting the grayscale values of the images into dimensional data. Based on the calculated dimensional data of each position, the software judges whether the measured values of each position are consistent with the designed dimensions of the drill pipe joint. The inspection time for each workpiece is about 6 seconds, and 15 photos are taken for one full circle of the joint. The number of photos can be defined by oneself according to needs. After the software system finishes analyzing and measuring the 15 photos of the joint, if every dimension in each photo is within the qualified range, the joint is a qualified product.

5. Conclusion

The automated production line for drill pipe joint processing designed and constructed in this study has been successfully put into actual production after installation and commissioning, with a cumulative output of hundreds of thousands of various types of drill pipe joints. By integrating multiple CNC machine tools, gantry manipulators, and optical thread inspection systems, the production line has established an efficient automated workstation, with a key breakthrough in the non-contact inspection technology bottleneck for large-pitch tapered threads, and independently developed detection algorithms and process methods adapted to such structures. At the same time, the production line has the capability of flexible switching between multiple specifications and can simultaneously produce products of different models, fully realizing the automation and intelligent upgrading of the production and manufacturing of short drill pipe joints for coal mines.

From the perspective of research limitations, the stability of the current production line under extreme working conditions still requires long-term verification, and the compatibility and adaptability for extra-large-size drill pipe joints need further optimization. Future research can be deepened in three aspects: first, building a full-lifecycle data monitoring platform for the production line by combining industrial internet technology to improve fault warning and maintenance efficiency; second, expanding the application scenarios of AI visual inspection to achieve more accurate identification and classification of thread defects; third, developing modular quick-change mechanisms to further reduce the time cost of switching between multiple specifications, promoting the development of coal mine drilling equipment manufacturing toward higher precision, higher flexibility, and intelligent direction.

References

- [1] Wang L, Wang F .Optimization of operating costs for hybrid manufacturing production mode based on wireless sensor networks and robots[J].The International Journal of Advanced Manufacturing Technology,2025,(prepublish):1-11.
- [2] Wang Xiaoyu, Zhao Zhi, Hua Chunlei, et al. Application of robot in flexible manufacturing system[J]. Manufacturing Technology & Machine Tool, 2012, (10): 63–67.
- [3] Fu Qiulin, Lu Qingdong, et al. Development Status and Prospect of industrial Robot in China[J], 2020, 56(10): 217-218.
- [4] Tian Dongzhuang, Chen Yanyu, Li Qing, Dong Mengmeng,et al. Reserch status and prospect of drill pipe thread used in coal min[J], Coal Geology & Exploration 2020, 56(10): 217-218.

- [5] Shi Zhijun, Yao Ke, Yao Ningping, et al. 40 years of development and prospect on underground coal mine tunnel drilling technology and equipment in China [J], coal Science and Technology, 2020, 48(4):1-34.
- [6] Guo Zhiliang. Design and Research of Loading and Unloading System for Truss Robot of CNC Lathe[D]. Dalian: Dalian University of Technology, 2020.
- [7] He Minjia, Jiang Wenming, et al. An Industrial Robot Suitable for Loading of CNC Machine Tools[J]. Mechanical & Electrical Engineering Technology, 2015, 44(08): 45-48.
- [8] TIAN Dongzhuang, A kind of gripper in industrial robot for grasping the drilling rod[J], Mining & Processing Equipment, 2009, 37(17): 45-46.
- [9] LU Zhenyu, Design and improvement of robot fixture [J], Robot Technique and Application, 2009.(05), 89-91.
- [10] LIAO Nengjie, MA Ping, OU Jianguo, et al. Design of control System of Truss Robot For Loading and Unloading [J], Machinery Design & manufacture, 2020.(12): 171-175.
- [11] LIU Linshan, LI Jianyong, et al. Research on control system of up-down materials truss robot for a CNC Machine[J], Manufacturing Automation, 2019, 41(09): 108-110.
- [12] WU Qiumei, ZHANG Mingzhu, et al. Research on Quantitative Detection Method of Tread Ring Gauge[J], Henan Science and Technology, 2019, (26): 50-52.
- [13] YAN Lu, Research on on-the-spot precision detection method of petroleum drill pipe thread [J], China Steel Focus, 2019.(01), 34-34+36
- [14] ZHANG Yao, ZHANG Yunbo, et al. Optical surface detection based on deep learning [J], Acta Physica Sinica, 2021. 70(16): 45-46.
- [15] WU Zhifeng, CHAI Xin, WANG Yabo, et al. Measurement of External thread size system based on machine vision Non-contact[J], Acta Physica Sinica, 2021. 70(16): 45-46.
- [16] China Coal Science and Technology Group Xi'an Research Institute Co., Ltd. A large pitch conical external thread detection device and method: 201811533417.9[P]. 2020-10-16.