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Development and Application of Robotic Technology for Intelligent Grinding of Welds

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Abstract: Large oil and gas conveying pipes are generally made of medium-thickness alloy steel plate welding. The API 5L pipeline steel pipe specification and GB/T9711.1-1997 standard put forward strict requirements for the high butt welding seam of the pipe end. Domestic pipe making enterprises generally use artificial grinding or semi-automatic welding grinding machine to repair steel pipe end weld. At present, there are many problems of poor accuracy and compliance, cumbersome production process, low automation and low labor efficiency. This paper, on the basis of the existing sand belt grinding machine development weld intelligent grinding robot, first using visual recognition technology, realize weld automatic recognition, using fuzzy control and neural network control mechanical arm motion and action, automatic decision grinding motion parameters and movement trajectory, ensure the welding pipe weld grinding quality standard, and improve the processing efficiency.

1. Introduction

Large oil and gas conveying pipe is generally made of thick alloy steel plate welding, the engineering of the pipe end butt welding high strict requirements, AP ISPEC 5L pipe specification and GB/T9711.1-1997 standard are clearly stipulated: 150 mm from the weld should be removed, after removing the inner weld beyond the steel pipe surface should be less than 0.5 mm, but not lower than the pipe body, grinding can not obviously hurt the parent material. At present, there are many main problems, such as poor accuracy and compliance, cumbersome production process, low automation degree and low labor efficiency.

The application and development of welding pipe weld intelligent grinding robot is mainly used in the internal and external welding seam grinding technology and equipment of straight seam and spiral buried arc welding pipe pipe end. The current internal and external welding grinding is completed by manual control internal welding grinding machine and external welding grinding machine, which occupy many stations, many operators, long material transportation time, and it is not easy to ensure the weld grinding quality. In order to solve the above insufficient problems of the existing grinding machine, the modern detection, control and network communication technology are applied to develop the buried arc welding pipe end internal and external welding joint grinding robot, so as to realize the automatic grinding of the internal and external welding joint.

2. Research Status and Development Trend at Home and Abroad

Foreign countries have developed a more mature commercial machine grinding and throwing robots, Typical examples are GE's steam turbine blade grinding system, ACME's complex curved biplex robot grinding system, the Finnish ORAS company, Japan's MOTOMAN robot company faucet robot grinding system, KUKA's chainsaw grinding system, And the Greek company ZENON's blade repair robot system, Domestic Langfang Zhitong Robot Company took the lead in developing the first domestic grinding robot system with independent intellectual property rights, which can be used for grinding and polishing of blades and curved surfaces. The application demand of industrial robots in the grinding industry is increasing [1-3]. The control accuracy of the robot, motion process path planning, grinding mechanism and process parameter optimization, and the achievements still need to be further studied and improved in the intelligent decision-making [4-6].

Since the first industrial robot came out in the 1960s, scholars and experts have sprung up in the field of robotics. With the birth of four major robot brands: ABB Robot Company of Switzerland, KUKA Robotics of Germany, FANUC Robotics of Japan and YASKAWA Robotics of Japan. In the 1970s, the field of robot polishing. Fu Z [7] et al. studied the influence of the robot grinding radius and grinding depth on the local stress field of welding, and proposed the grinding parameters compared with the grinding radius and grinding depth. Mohammad [8] used the IRB2600 industrial robot produced by ABB to propose a polishing program based on neural network and genetic algorithm, solving the problem of overpolishing or underpolishing in traditional polishing because the polishing parameters have constant values along the surface. In order to solve the problem of complex and inefficient using robot teaching polishing method, Huang [9] et al. proposed an offline programming polishing robot scheme based on force control. XIE [10] et al. established a robot flexible grinding system, analyzed the influence of processing process parameters such as contact angle and motion attitude on grinding surface quality and grinding efficiency, and established a quantitative regression model. Xie Xiaohui [11] proposed a robot polishing method based on offline programming, which records the grinding trajectory points, generates a polishing program, and realizes the robot offline polishing.

Zhao Ji's team [12, 13] designed the adsorption mobile robot grinding system based on binocular camera in order to realize the automatic welding of the weld seam after welding of large structural parts. Nguyen [14] uses laser vision to develop a weld detection and defect detection system to guide robot welding operations. LI [15] proposed a robot ring seam tracking system for pipe welding robot based on analyzing the relationship of laser reflection, camera, laser surface and welder.YE [16] uses a model and expectation maximization algorithm to use laser lines to project weld surfaces and receive reflections to track and extract weld shapes. Yang Pengcheng [17] collects the workpiece surface contour data points based on the laser displacement sensor, restores the weld morphology, and detects the weld surface defects. He Yinxi [18] thick plate weld, extracting a typical joint weld extraction algorithm, can realize the effective extraction of laser stripes, eliminate the impact of arc light. Guo Liang [19] uses rotating arc and laser vision dual sensing mode to collect current and image signals, tracking the broken weld, to achieve good identification and tracking effect. High eastward [20] obtains the weld position information by magneto-optical sensing method, and uses the optimized Kalman filter to identify and track the weld profile.

In 2002, Baoji Petroleum Steel Pipe Co., Ltd. solved the technical requirements, proposed the sand belt grinding, completed the research and development of external weld sand strip grinding technology, and obtained the recognition of west-east gas transmission project department. This technology has achieved remarkable results, reduces the production cost, improves the efficiency, and is still in use in large diameter welded pipe production line. Since then, many domestic research institutions have also continuously improved and developed a new pipe end weld grinding machine, but its structure basically continues the grinding belt wheel pressure grinding method, and its grinding process has always maintained a single surface grinding. In 2015, Zhang Jijian of Shandong University improved the double-sided grinding structure for the grinding machine of the spiral welding pipe production line. Although the domestic pipe end grinding equipment has made great progress, but it still has the following deficiencies: low degree of intelligence, foreign advanced grinding machine basic automation, without manual operation, can automatically find welding, automatic grinding; and domestic grinder is generally manual operation, low degree of automation, no automatic weld welding and automatic grinding function. Grinding parameters are not optimized: the design parameters are not calculated by the system theory or optimized for welding pipe grinding, there is a design redundancy or waste phenomenon, and the grinding quality needs to be improved.

3. Existing Problems in Welding Pipe Weld Seam

At present, domestic pipe making enterprises generally use artificial grinding steel pipe end weld, artificial grinding has the following deficiencies:

(1) The production efficiency is low. Under normal circumstances, it takes about 10 minutes to manually grind a 150 mm long spiral weld on the steel pipe, which takes a long time;

(2) It is difficult to guarantee the grinding quality. The master worker grinds with a grinding wheel, the grinding quality is unstable, and if you are not careful during the grinding process, the grinding wheel will damage the pipe, affect the quality of the steel pipe, and also bury the quality hidden danger for the expansion and chamfering of the subsequent work. Rework many times.

(3) The labor intensity is high, the operator is easily fatigued, and the dust and noise are large, which affects the physical and mental health of the operator.

(4) The cost is high. Manual grinding requires a large amount of labor, and the consumption of grinding wheels and manual grinding machines is large, resulting in a great increase in production costs.

(5) Poor safety, in the grinding process, there is an unsafe factor that the manual grinding wheel is fragile and hurts people.

Some enterprises also use semi-automatic internal welding grinding machine and external welding grinding machine, which can move along the guide rail, the grinding height can be adjusted, the material weld height is generally 2~3mm, the operator first adjust the internal welding grinding machine coarse grinding internal welding, and then use the internal welding grinding; then adjust the external welding grinding machine coarse grinding the external welding, and finally use the external weld grinding. The residual height of the internal and external weld joints after grinding is generally 0-0.5 m m, and the length is 200-300 m m. At present, there are many problems of poor accuracy and compliance, cumbersome production process, low automation and low labor efficiency. Although some people in China have designed and developed the weld sand belt grinding machine to replace manual labor and achieve automatic grinding, it still needs too much manual control operation, without realizing intelligent decision-making and intelligent control.

4. Key Technology of Weld Intelligent Grinding

Welding grinding robot is a kind of grinding robot. In recent years, with the development of robot technology at home and abroad, the domestic demand for industrial robots is increasing, especially the demand for grinding robot. Robot grinding processing related technology is one of the new directions that should pay attention to and increase the investment in research and development. With the increasing market competition, the enterprise to product quality requirements is higher and higher, at the same time personalized production and efficient production demand is increasing, and social labor costs are rising, at the same time industrial robot technology is gradually developed, in order to adapt to the demand of production enterprises for intelligent grinding technology, the study of intelligent grinding robot is imperative.

4.1. Intelligent Grinding Optimization Design of Weld Joint

Analysis of grinding process, kinematic analysis of grinding work process, develop intelligent grinding robot, design reasonable mechanism body and related auxiliary system, complete the design of the fuselage parts, machine vision hardware part, perform mechanical arm, grinding head device, dust removal system, cooling system, lubrication system design, etc.

4.2. Intelligent Weld Identification Technology

The key to the acquisition of weld morphology characteristic data lies in the dynamic positioning of welds and weld height identification (3 D measurement) in a complex industrial environment. The morphology characteristic data is the premise of realizing accurate weld grinding and provides basic data for planning robot grinding trajectory. The weld detection system uses laser visual detection technology to scan and sample the weld profiles of different sections of steel pipes, and analyze the characteristic curve data after sampling. First, the original image is filtered, refined, and the feature curve extraction, and then the feature curve is filtered, smoothed, pattern matching, feature point extraction, fitting, interpolation, etc.

First according to the requirements of image device camera and sensor selection, and then the structure parameters of image acquisition device simulation optimization, select image processing algorithm, establish weld 3 D measurement model, implement workpiece positioning, implement the detection weld, weld feature extraction, intelligent recognition, automatic tracking, planning manipulator joint path, determine the grinding head grinding attitude, establish binocular stereo 21/2D Visual Servo System.

Binocular vision of the 2 was used1/2D visual servo system enables the robot to complete the intelligent acquisition, processing and feature extraction of weld image; image transformation and positioning, mapping target object information from image feature space to the image feature space; weld tracking, designing optimal control law according to Lyapunov method, realizing visual guidance, completing online tracking task, establishing visual servo control model, completing visual intelligent decision, ensuring the robot has intelligent visual servo function, and ensuring the accuracy and robustness of the system. The characteristic curve of weld area is processed by graphics software to obtain weld topography characteristic data. Including the coordinate position of the two edges of the weld and the height of the weld, the treatment interface of the weld detection system is shown in Figure 1 below.

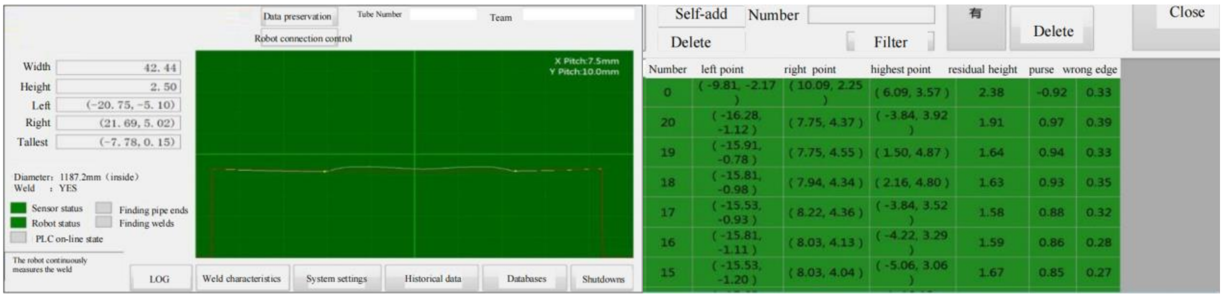

Figure 1: Processing interface of weld detection system

4.3. Intelligent Decision-making Technology of the Control System

Intelligent decision making technology of control system, analysis and processing of model uncertainties and constraints in visual servo system, intelligent learning and decision making technology based on fuzzy algorithms and neural networks. Plan the weld grinding motion trajectory, analyze the weld positioning process and grinding process, adopt the fuzzy control strategy based on the parameter adaptation of the robot body and mechanical arm, optimize the dynamic parameters, adjust the position of the visual measurement system, and ensure the good dynamic characteristics, fast dynamic reaction speed and high steady-state accuracy. The center movement track of the grinding wheel is calculated using the detected weld morphology characteristic data. If the weld height is too high, the whole strip weld will bring great impact on the equipment, and greatly shorten the service life of the grinding wheel sand belt, so according to the height of the weld, multiple grinding is completed. According to the characteristics of straight joints and spiral welds, different grinding movements are used.

The free motion state and the end contact operation state of the grinding robot were controlled separately. The trajectory tracking controller of the mobile platform and the manipulator is established to verify the effectiveness of the established controller through simulation analysis. Analyze the hybrid control and neural network control strategies, and the implementation method of the impedance control, establish the operating force impedance controller during the manipulator contact operation, and conduct the simulation analysis to verify the effectiveness of the controller.

4.3.1. Planning of Straight Weld Grinding Movement track

Straight weld grinding adopts linear grinding + arc grinding running track, as shown in Figure 2 below.

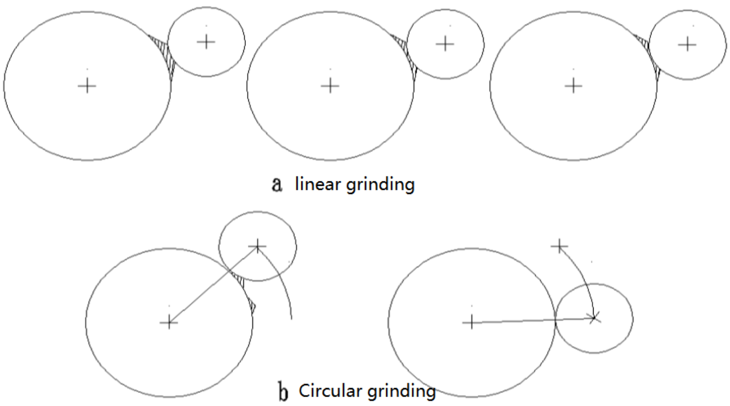

Figure 2: Schematic diagram of linear grinding and circular grinding

(1) Linear grinding motion trajectory

According to the linear scale relationship, the grinding wheel center motion trajectory of each measured circular section is obtained by Equations 1 and 2.Track equation for linear grinding of the grinding wheel center (±for outer and inner welds respectively):

$$X= (Xm-X0) * (R \pm (r + OFFSET)) / L + X0 \tag{1}$$

$$Z = (Zm-Z0) * (R \pm (r + OFFSET)) / L + Z0 \tag{2}$$

Formula L = √((Xm-X0) 2 + (Zm-ZO) 2);
OFFSET: Compensation amount for each grinding;
r: grinding wheel radius;
R: the radius of the steel pipe;
(X0, Z0): the center of the weld section 0;
(Xm, Zm): Two-point midpoint of weld connection M.

(2) After the arc grinding, most of the welds are grinding off, leaving a small number of welds on the two edges of the weld. The weld is divided into several sections, within each section by the method of arc grinding.Track equation for arc grinding of the grinding wheel center (±for outer and inner welds respectively):

$$X= (x-X0) * (R \pm r) / R + X0 \tag{3}$$
$$Z= (z-Z0) * (R \pm r) / R + Z0 \tag{4}$$

Formula (x, z) are the coordinates of the two edges of the weld (X1, Z1), (X2, Z2).

4.3.2. Grinding Motion Trajectory Planning of Spiral Weld Seam

Straight weld requires straight grinding and arc grinding to better complete a weld grinding, grinding spiral weld, using the method of spiral grinding, grinding wheel along the weld spiral movement, grinding wheel sand belt cutting steel pipe axial weld, because the curvature of the axial weld, weld ends and grinding wheel sand belt full contact, weld two edges can be fully grinding. The movement direction of the spiral wheel is shown in Figure 3 below.

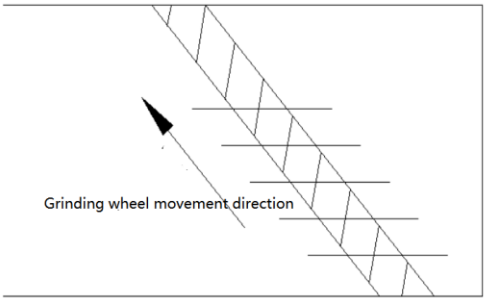

Figure 3: Schematic diagram of the spiral grinding

(1) The spiral grinding trajectory equation of grinding wheel: (± αfor left and right helix).

$$X = (R \pm (r + OFFSET)) * Cos (\pm\alpha) \tag{5}$$

$$Z = (R \pm (r + OFFSET)) * Sin (\pm\alpha) \tag{6}$$

$$Y = S * |\alpha| / 360 \tag{7}$$

In the formula, S = 2 *π* R * Tg (90-β);
β: Spiral Angle,α: Step Angle.

At the gradually changing Angle, find the coordinates of the spiral motion of the grinding wheel respectively by using formula. 5~7, and grind the spiral weld according to this trajectory. Similar to the straight grinding of straight joints, spiral motion, multiple grinding,

(2) Optimization of the spiral welding grinding method Due to the inherent reasons of the spiral welding molding method, the edges on both sides of the weld are concave. If the welding edge is to be fully sharpened, the wound will inevitably be hurt to the attached base material. The optimization scheme is shown in Figure 4 below.

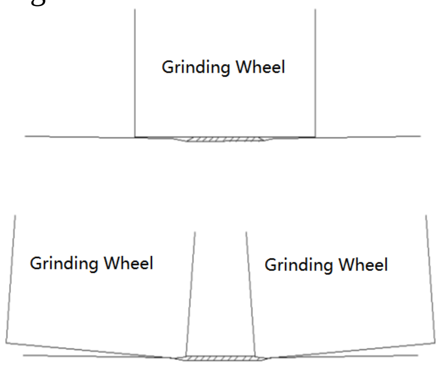

Figure 4: Schematic diagram of spiral weld grinding optimization

4.4. Construction Technology of Intelligent Grinding Expert System

The key to the construction technology of the intelligent grinding expert system is the establishment of the knowledge acquisition mode and the knowledge base, and the determination of the middle reasoning control strategy of the reasoning machine. Establish the weld intelligent grinding process expert system, establish the intelligent grinding model, optimize the grinding process. Parameter optimization based on fuzzy algorithm and grinding process knowledge base and expert system, using active learning method, using heuristic reasoning design machine, using fuzzy algorithm to solve the control and decision of sand belt movement track and working parameters, to ensure the optimal processing process, improve grinding efficiency and ensure grinding quality.

By grinding the man-machine interface of the expert system, the user can input the processing requirements and the initial processing conditions, select the optimization target, and determine the reasoning machine to start the work. The reasoning machine searches the database according to the user's input. If there are the processing initial conditions and processing requirements similar to the user input, the grinding parameters of this example are used as the reasoning result, and these parameters can be used in the grinding process when the user is satisfied. Otherwise, the reasoner turns to the rule library, uses the heuristic rule, searches the rule library, deduces the range value of the grinding parameters, then selects the corresponding model in the model library, analyzes the model, determines the constraints, and then optimizes the parameters according to the previously selected optimization target to obtain the optimization results. If the user has questions about the result, he can turn to explain the interpretation subsystem to understand the reasoning process, and the optimization result can be used for the grinding process upon confirmation.

5. Engineering Lication

The application of intelligent grinding pipe welding robot has the following characteristics: (1) suitable for internal and external welding joint grinding at straight seam and spiral buried arc welding pipe end, steel pipe specifications: steel pipe outer diameter: 508~ φ1420mm; length: 8000mm~12000mm; wall thickness: 6.4mm~40 mm; grinding length: 0~300mm. 0 m (set). (2) The internal and external welds can be grinding at the same station to meet the requirements of production beat. Straight joint grinding can be performed simultaneously at both ends of the steel pipe. Spiral joint joint grinding should be completed at two stations respectively, with the number of grinding roots > 9 roots / hour. (3) After the grinding, the following effects are achieved: the grinding does not hurt the base material, and the weld residual height meets the standard requirements is shown in Figure 5 below.

Figure 5: Engineering Application of Intelligent Grinding Robot for Welding Seam of Welded Pipe

The application of weld intelligent grinding robot technology can improve the economic benefit from the following aspects: (1) shorten the grinding time, the existing non-intelligent grinding machine can control within 4-5 minutes, develop intelligent grinding robot can shorten the grinding time of single welding, greatly improve production efficiency; (2) improve the grinding quality, optimize the grinding process parameters in the grinding process, reduce the consumption of grinding wheel consumables and save production cost; (3) reduce the number of workers, intelligent grinding robot replace workers grinding and save labor cost. To sum up, the economic benefits of intelligent welding pipe and weld grinding robot brings to enterprises are very attractive, and its social benefits are also very good.

6. Conclusion

On the basis of the existing sand belt grinding machine development intelligent grinding robot, first using visual recognition technology, realize weld automatic recognition, reuse fuzzy control and neural network control the movement and action of mechanical arm, automatic decision grinding motion parameters and trajectory, ensure the welding pipe weld grinding quality standards, at the same time improve the processing efficiency. The application of welding seam intelligent grinding robot technology can drive the development of related robot technology application field, promote the rapid growth and development of enterprises, and improve the social competitiveness of related enterprises in the industry, and even improve the intelligent manufacturing level of related equipment manufacturing industry in China.

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