EXPLORATION OF CAD/CAM TECHNOLOGY FOR CONSTRUCTION OF JACKET ON OFFSHORE PLATFORM

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ABSTRACT: *The purpose of this study is to improve the efficiency and quality of jacket construction process, and to improve the existing production and development technology of fitting pipe in offshore platform. In this research, the design and construction process of jacket was introduced. Starting from the cutting drawing design of jacket pipe fitting and the realization of numerical control (NC) automatic cutting, the intersecting line calculation and motion simulation method were used to realize the integrated development of computer aided design (CAD) system for jacket pipe fitting cutting design and computer aided manufacturing (CAM) system for cutting and manufacturing. The results showed that the complementary and matching of the two systems was the key to complete the jacket construction. In summary, the CAD/CAM technology for the entire process of jacket pipe fitting cutting from design drawings to production objects can lead to more automated, efficient, and intensive integrated production.*

KEYWORDS: *Jacket; CAD/CAM; Intersection line; Pipe fitting cutting; NC*

1. INTRODUCTION

With the rapid development of economy, human beings have an increasing demand for natural resources, and the development direction of resources is more and more inclined to the Marine field. Jacket platform, as one of the most widely used offshore platform mining structures, has the characteristics of strong adaptability, resistance to natural load, low operation and maintenance cost, simple structure and so on, and has become a common platform for Marine energy exploration and mining in China. However, jacket platforms face increasingly complex structural requirements and the need to be more water resistant and reliable. How to shorten the cost and cycle of construction engineering and improve the technical efficiency of construction process under the condition of meeting the requirements of jacket design
and manufacturing quality has become an urgent problem to be solved in the development of offshore platform jacket construction technology.

A jacket consists of a hollow conduit (or leg column) and a crossbar connecting the leg column. Steel trusses are driven into the seabed to support the fixed platform above. Its construction process is mainly based on cutting phase welding, and it is composed of a steel structure with a large diameter and a very thick inner wall. Therefore, the construction process is complex, and the application of computer aided technology in the field of Marine engineering can greatly reduce the production difficulty. CAD/CAM technology for jacket construction [1] refers to the matching and application of computer-aided design and computer-aided manufacturing technology in offshore jacket construction system, which assists relevant personnel to develop construction technology system. According to the different intersecting types of pipe joints, and based on the application of Auto CAD design [2, 3], pipe fitting designers can no longer use the single intersecting automatic drawing design system in order to meet the current large and complex jacket structure. Similarly, the production and manufacturing department needs to update and improve the system for pipe fitting cutting and processing by applying design drawings, and re-develop the applicable NC movement program of pipe cutting machine [4, 5]. In this paper, the CAD/CAM system for jacket pipe fitting cutting was designed and established. The design and construction process of jacket needs to be coordinated from various aspects, and the detailed design steps are also complicated. Therefore, it is necessary to fully consider the construction specifications of pipe rack and master the computer program-aided technology, and to carry out process design and analysis along the following three stepefore construction. The first step is the overall design to determine the overall structural form and overall construction policy. The second step is detailed design to realize the construction design, which is an effective way to achieve the organic combination of design and

manufacturing. It is embodied in the division of construction process stages and construction areas, and the management of construction drawings and work charts. Therefore, the cutting drawings of pipe fitting platform structure should be closely related to the real-time processing state and processing process in real construction. It should design a CAD system that matches the practical application requirements, complete the planning and construction of the adaptive aspects of the process system, and meet the various functional requirements in the production design.

To sum up, in this research, the improvement of computer aided drawing design and NC production technology of jacket were taken as the direction of efforts to establish the correlation system of cutting design CAD of jacket and NC CAM of pipe cutting machine. It is hoped that the combination and penetration of CAD/CAM technology can achieve the integration of design and manufacturing.

2. METHODOLOGY

2.1 Calculation Model of Jacket Intersecting Line

As the large steel pipe structure of the jacket is composed by cutting and welding of various pipe fittings, the development and construction of the jacket focuses on the application and development of the pipe joints, the establishment of the overall coordinate system, and local coordinate system of the pipe support platform. The design form and connection position of pipe joints during pipe rack welding are important factors affecting the construction accuracy and safety of the entire pipe rack. Welding groove cutting is required at the end of connecting pipe fitting [6]. Therefore, drawing a single drawing of pipe fitting cutting and forming is required for design and production. And the calculation model of the intersecting line should be constructed based on the single-piece structure of the jacket.

the intersecting line path, the cut piece was rotated. According to the equation of intersecting line, the torch would move back and forth in the direction of the branch line axis, complete intersecting line cutting, and establish the intersecting line calculation model. The following is an example of intersecting line to analyze the construction process of intersecting line calculation model. Taking the intersection point of the two axes of the main pipe and the branch pipe as the origin O, the equation for calculating the intersecting line in the X-axis and Y-axis directions is as follows:

The main function of coordinate system is to show the type characteristics and definition of pipe fitting intersecting with the actual plane graph. The coordinate system of the overall structure of the jacket platform can provide an overall general guidance, and it is also the lofting and unfolding diagram of the pipe fitting structure. In this study, according to the requirements of the specification, the pipe fittings were classified by number. The center position of the platform bottom surface was taken as the central point O, and the X axes were taken respectively on the platform bottom plane, with the right direction being positive. On the Y-axis, the arrow was pointing in a positive direction. The Z-axis was taken perpendicular to the bottom plane of the platform, and the Z-axis pointing position was the direction in which the jacket was vertically high, and the upward direction was a positive value. The coordinate system of the jacket structure and the number of its joints were established. The local coordinate system of pipe nodes was mainly composed of the main pipe. The main pipe coordinate system was represented by uppercase X, Y and Z, while the branch pipe coordinate system was represented by lowercase X, Y and Z. The axis lines of the main pipe and branch pipe were respectively set as the X axis, Y axis and Z axis.

The intersecting line calculation software used by the NC pipe cutting machine for jacket cutting shall start the intersecting line model calculation after inputting non-graphical information such as geometry and position parameters. Different types of intersecting pipe nodes were calculated with their corresponding mathematical models. Taking the mathematical model of pipe intersecting as calculated with their corresponding mathematical models. Taking the mathematical model of pipe intersecting as an example, the relevant parameters involved were branch axis section, main section, normal section, groove angle, cutting angle and so on. When the torch operated the cutting command according to

$$Y = \frac{1}{\sin\ \alpha}\sqrt{\left(\frac{D}{2}\right)^2 - \left[r\sin\left(\theta - \beta\right) + e\right]^2} + \frac{r\cos\left(\theta - \beta\right)}{\tan\ \alpha} + \delta \quad (1)$$

The above formula 1 is the coordinate representation of the intersecting line on the Y-axis. Among them, α represents axis intersection angle, β represents the torsion angle, D represents the diameter of the main pipe, d represents the diameter of the branch pipe, θ represents an angular increment in the x-axis direction, r is the radius of the inner wall of the branch tube calculated by the diameter and wall thickness, e is eccentricity, and δ represents centrifugal value.

$$X = \left(\frac{d}{2} - t \right) \frac{\pi}{180} \theta \quad (2)$$

The above formula 2 is the coordinate representation of the intersecting line on the X-axis.

Based on the establishment of the intersecting line mathematical model, in order to realize the calculation of the intersecting line of pipe sections, the following pipe joints of lap type are further explained and analyzed to simulate the intersecting line composite curve. The pipe joint of the pipe fitting was formed by the welding combination of the main pipe and branch pipe, and the coordinate position of the pipe joint was generally determined with the main pipe as the reference position. The coordinate origin of the main branch pipe coincided with the intersection point of the main pipe and the branch pipe axis. The intersection of two stereos when combined together in different ways is called the intersection of two stereos. The intersecting lines formed by their surfaces were called intersecting lines, which were the common lines of the two surfaces and the dividing lines of the two bodies. The point on the intersecting line was the common point of two solid surfaces. Figure 1 shows the intersecting line synthesis curve under the calculation process of lap type pipe node. The intersecting line of the main pipe and branch pipe is calculated as model 1, and the intersecting line of the lap pipe and branch pipe is calculated as model 2, respectively corresponding to the curves in the figure. The black dot square curve is intersecting line 1, and the red dot circle curve is intersecting line 2. Y axis is the circumferential angle, and the moving distance of cutting torch is Y. For each sampling point, the point with a larger Y value should be taken as the final sampling point. And the green triangular curve is the composite curve of intersecting lines.

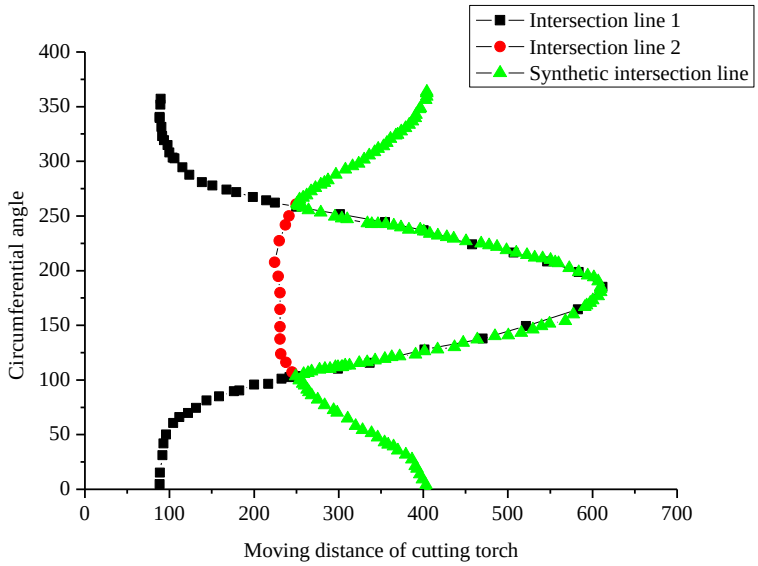

Figure 1. The synthesis of intersecting lines of lap joints

Based on the division of pipe fitting coordinate system, the intersecting line calculation model was established, and the intersecting line model provided theoretical basis for pipe fitting cutting design and NC manufacturing.

2.2 CAD System for Pipe Cutting Design

In the production design of jacket, the pipe fitting cutting drawing was designed based on the single-line drawing structure of jacket, and the cutting design and production system of jacket was developed based on the intersecting line calculation results. In the past, Auto CAD was mostly used for two-dimensional design of offshore platforms, which can no longer meet the increasingly complex design requirements, and three-dimensional software has better application functions [7, 8]. China National Offshore Oil Engineering Co., Ltd. developed a pipe cutting design system based on the Auto CAD platform, namely the PTMAK system. PTMAK system is developed on the basis of Auto CAD platform. Based on the design framework of three-dimensional single line diagram, the internal calculation was started by receiving orders, and the calculation of pipe fitting intersecting line of various intersecting node types was automatically completed as the core, and then the intersecting line sampling data drawing was

conducted within the system [8]. And in the drawings, the dimensions of the pipe fittings were marked. The whole system structure diagram can be divided into 8 small modules according to function modules, and the function performance of each function module is shown in figure 2.

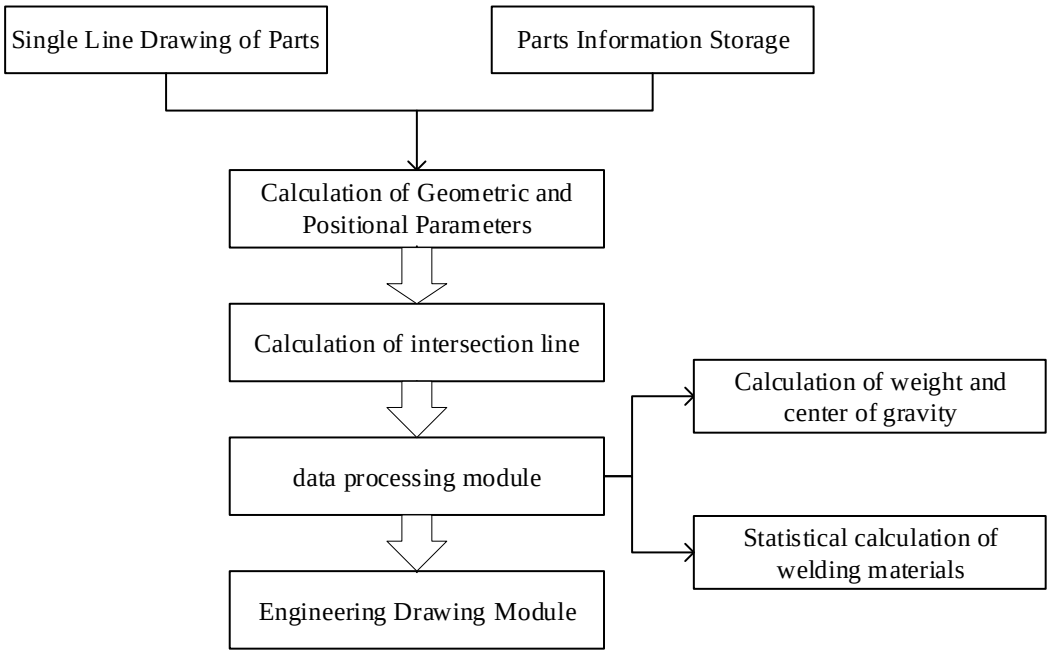

Figure 2. Structure of CAD system for pipe cutting design

First, part information generation module. The module used the input interface of certain data form to input parameter information, such as number, wall thickness, diameter, type and other non-graphical parameters that can't be represented by graphs. Through Auto CAD's data dictionary function, a new object was created and stored in Auto CAD database. Parameter data was associated with geometric entities, and parameter information can be easily called and modified.

Second, part geometry and position parameter calculation module. The calculation basis of intersecting line was determined by the geometry and position parameters of pipe fitting. After the corresponding calculation of geometric parameters and positional parameters, the obtained data would be stored in the data dictionary, so as to provide data support for the calculation of intersecting line.

Third, intersecting node type judgment module. Based on the graph information of single line graph of intersecting node of PTMAK system, the calculation of intersecting line can only be started by inputting non-graph information to distinguish entity types. This module was mainly used to determine the node type. At the same time, the system would consider the reliability of parameter input and carry out corresponding fault tolerant processing.

Fourth, intersecting line calculation module. On the basis of the last module completing the type judgment, different types would issue different commands, and then the system would automatically calculate the intersecting line. At the same time, the calculated results were saved to the data storage module.

Fifth, data processing module. After the calculation of the intersecting line, various key point data obtained from the calculation of the pipe fitting were extracted. If there were multiple intersecting lines, data fitting of multiple intersecting lines was required, that is, the intersecting lines were synthesized according to the Y value maximum criterion.

Sixth, engineering drawing module. This module was the output module of pipe fitting cutting design. According to the production design requirements, the cutting design drawings of each pipe fitting were drawn, and the scale data information was marked in a summary manner. The single piece drawing in the drawing type was the expanded drawing after branch pipe cutting according to scale.

Seventh, weight and center of gravity calculation module. In the construction of jacket, the weight and center of gravity of pipe structure were important design data in production design. According to the geometric data of pipe fitting calculated by intersecting line, the weight and center of gravity of main pipe, plate, cone, ring and other components were calculated respectively, and the weight and center of gravity of all components in a single drawing were synthesized.

Eighth, welding material calculation statistics module. In order to complete the calculation of the amount of welding material in the pipe joints, it was necessary to calculate the weld volume at the pipe joints. In the process of welding process design, in addition to the design of welding process parameters, welding material calculation and welding material product summary was also an important content.

Based on the basic platform of Auto CAD and the three-dimensional single-line diagram structure of jacket, PTMAK system was developed and designed in a secondary way, which included eight functional differentiation modules.

2.3 CNC CAM System for Pipe Cutting Machine

In the construction of jacket, a large number of steel pipe members would be applied. Compared with the limitations of manual cutting of pipe fitting, CNC automatic pipe cutting machine gradually replaces manual cutting. Its advantages include fast cutting, many styles and high precision. Currently, automatic pipe cutting machine has been basically used in the cutting of pipe fittings with the diameter of less than 14 meters [9]. The welding groove of intersecting line was cut and machined, the motion control of pipe cutter was analyzed, the mathematical model of cutting moment, position and posture motion was established, and the more advanced NC system of pipe cutter was developed.

To realize automatic pipe fitting cutting, it was necessary to develop corresponding CNC software system for pipe cutting machine movement control. The system mainly included NC programming and movement control module of pipe cutter [10]. Among them, the former mainly calculated different types of intersecting lines, and then generated NC code. The latter recognized NC code on the basis, implemented corresponding motion control, and completed intersecting line cutting.

The CNC system of pipe cutting machine involved complex intersecting line calculation and corresponding development of motion control. Therefore, when developing the system interface, the route motion module should be considered. The underlying developers were used to design specific interfaces to communicate with the underlying data, and different application functions were programmed according to the intersecting of various types of pipe fittings. By dividing the software system modules, system development techniques can be effectively improved. Figure 3 analyzes the NC programming module, and its structure flow is shown as follows.

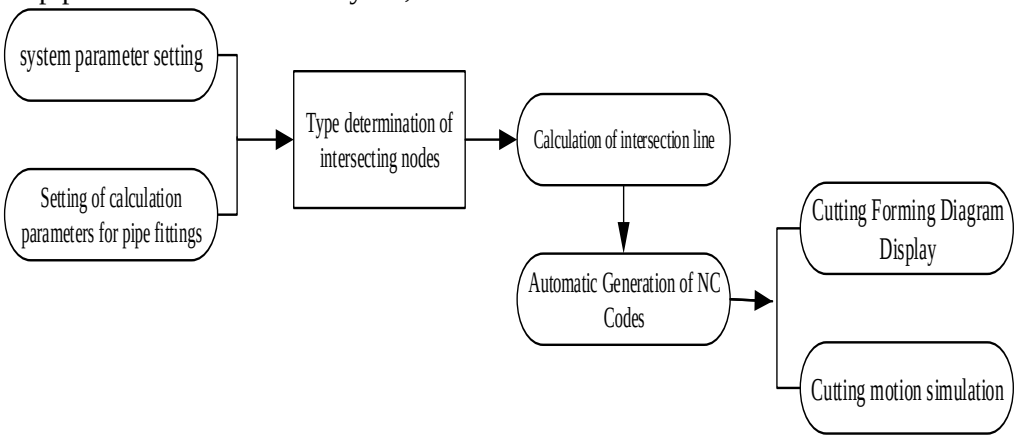

Figure 3. Process of NC system programming module of pipe cutter

In the system parameter setting module, software system parameters, mechanical system parameters and processing process parameters were related to the type of pipe cutting machine and process flow in actual production. The three types of parameters participated in the calculation of NC code. In the pipe fitting parameter input module, the NC software of pipe cutter was input to the system according to the geometric parameters and position parameters of pipe fitting calculated by PTMAK system. In the judgment module of intersecting node type, the judgment can be completed according to all kinds of input parameter information. The intersecting line calculation module contained all kinds of intersecting line calculation models. In the NC code automatic generation module, according to the calculation data of the intersecting line and the requirements of the cutting machine process design, the movement path of each axis during cutting was obtained. In the cutting and forming drawing display module, the cutting and forming drawing was automatically drawn according to the intersecting line data obtained by calculation, and the NC data was formed by comparing with the single drawing. In the cutting motion simulation module, Open Graphics Library (OpenGL) technology was used to realize the movement simulation of pipe fitting

intersecting line cutting, the position motion control of cutting torch during intersecting line groove cutting, and the real-time simulation and transformation of pipe fitting cutting state.

3. RESULTS AND DISCUSSION

3.1 Simulation Results of OpenGL Torch Movement

According to the slope mathematical model of intersecting line and the cutting torch movement control model, the design data of intersecting line was converted into processing data. The simulation of pipe fitting cutting motion machining was a vivid mapping of the process of machining in the computer and an important embodiment of CAD/CAM technology. The purpose of machining simulation was to effectively verify the correctness of NC code generated by CAD/CAM, whether the tool and workpiece collide and interfere with each other in the process of reprocessing, and the motion track, etc. In the process of pipe fitting intersecting line cutting, NC code was automatically generated by NC software. Compared with manual operation, automatic cutting design can effectively reduce processing time, improve operation efficiency and reduce error rate, with practical characteristics. OpenGL was a graphics programming interface, which was widely used in graphics programming development. OpenGL database was used for some program development, and OpenGL was widely used because of its fast running speed, low resource consumption and good portability. Open GL working pipeline was used to realize the CNC programming of pipe fitting cutting on the NC software of pipe cutting machine after the completion of the drawing of pipe fitting cutting design and the calculation of pipe fitting position parameters in PTMAK system.

In the process of motion simulation, a timer was used to extract sampling points and form a sampling point trajectory. According to the trajectory of sampling points of cutting torch, the pipe position and the torch posture were redrawn in real time to complete the torch trajectory motion simulation. With the simulation system, the NC code can be quickly detected before the intersecting line was actually processed, and the correctness of the code and the motion track can be verified. While the pipe cutting machine was running and processing, it was necessary to track the torch's moving path in real time. On the OpenGL simulation platform, pipe fitting cutting motion simulation was carried out. At the same time, cutting torch movement path tracking and movement track data were displayed on the simulation interface. The format of the track code segment was T-x-y-c-Z-a-f. Where, T represents the program label, x, y, c, Z, and a represent the movement locus of cutting torch in each axis position, and f represents the feeding speed of cutting torch. The X-axis movement of the pipe fitting itself was one of the motions of freedom, and the parametric movement control of the torch was reflected in the movement operation in four directions, including c axis, a axis, y axis and Z axis. Among them, the first two were the axis of rotation, and the y and Z axes were the linear motion axes.

In the specific pipe fitting cutting process, the system would automatically complete the intersecting line calculation and generate the corresponding NC machining code according to the cutting process requirements after setting the corresponding pipe frame geometry, position parameters and non-graphical information. The NC processing code was read with OpenGL simulation technology, and the state of cutting torch position movement was simulated in real time to complete the verification of NC code.

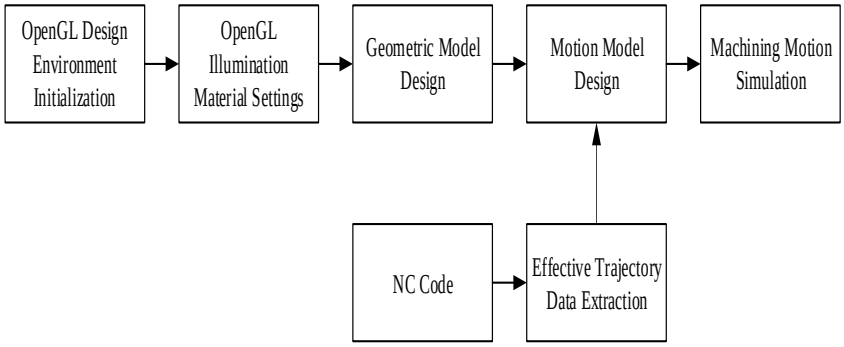

Figure 4. The realization flow of pipe fitting cutting OpenGL motion simulation system

As shown in Figure 4, the initialization of the OpenGL design environment was mainly to initialize the graphics pixels, which was the basis for the animation effect display. OpenGL lighting material settings were mainly calculated by simulating natural light to make two-dimensional

plane plans more three-dimensional. Geometric model design was mainly the model design of pipe fitting and cutting torch. Effective trajectory extraction lied in verifying the correctness of NC code, and extracting the motion data of the leading segment trajectory, the intersecting line trajectory segment, and the leading terminal trajectory. The motion model design was mainly derived from matrix operation in the system. Pipe fitting cutting movement simulation was to use the counter to extract the movement data of the sampling point. If the counter value was less than the total number of sampling points, then the pipe fitting and the cutting torch were redrawn, and finally form an animation display was formed. The calculation of the trajectory simulation was completed until the counter value was greater than the total number of sampling points. The significance of simulation technology in NC movement can provide cutting torch path simulation before actual processing, which directly and more accurately reflected the application of NC system of pipe cutter in actual cutting pass construction, and reduces unnecessary waste of pipe rack materials and labor cost.

3.2 Application Of CAD/CAM Technology

The part information generation module of PTMAK system was used to input the non-graphic information parameters of each pipe node in the system parameter dialog box, such as pipe fitting diameter, wall thickness, groove angle at the connection, etc., which was equivalent to completing the preparation work before automatic drawing. The command was input in the Auto CAD system, and each pipe fitting was selected in turn according to the system prompt. The system would start internal calculation and draw the single line diagram of Auto CAD model, including the pipe fitting cutting expanded drawing with intersecting groove and its forming size data. Information such as 0° and 180° bus position, pipe diameter, and wall thickness were marked in the pipe fitting cutting expansion diagram. The forming size included the specific data of pipe fitting length and the specific data of left end and right end intersecting line. In the drawing, the key position points were drawn to determine the relative positional relationship between the pipe fittings, and the welding profile was drawn on the main branch pipe to provide a basis for subsequent welding assembly work.

After PTMAK system was used to calculate cutting design drawings and pipe fitting position parameters, the next step was to realize pipe fitting cutting NC programming on the CNC software of pipe cutting machine. After reading the NC code, it was converted into a motion control command, and the CNC cutting machine was controlled to automatically complete the processing of the pipe welding groove.

The application of CAD/CAM technology in offshore platform brought a series of benefits. Compared with relying on human construction, the use of computer-aided technology reduced the intensity of designers' work and the cost of production and processing. Figure 5 and figure 6 show the effect of the application of CAD/CAM technology in reducing input. In addition, the application of CAD/CAM can improve the quality level and productivity. Figure 7 and figure 8 show that the application of CAD/CAM technology can improve the efficiency. Therefore, CAD/CAM technology system has good practical use value.

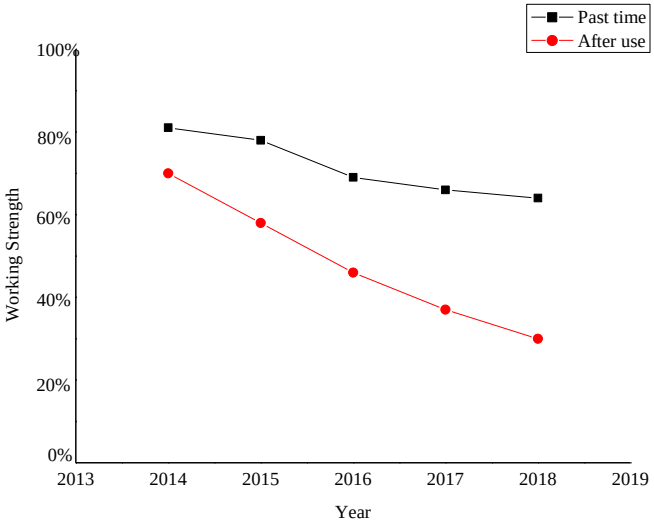

Figure 6. The effect of CAD/CAM technology on reducing work intensity

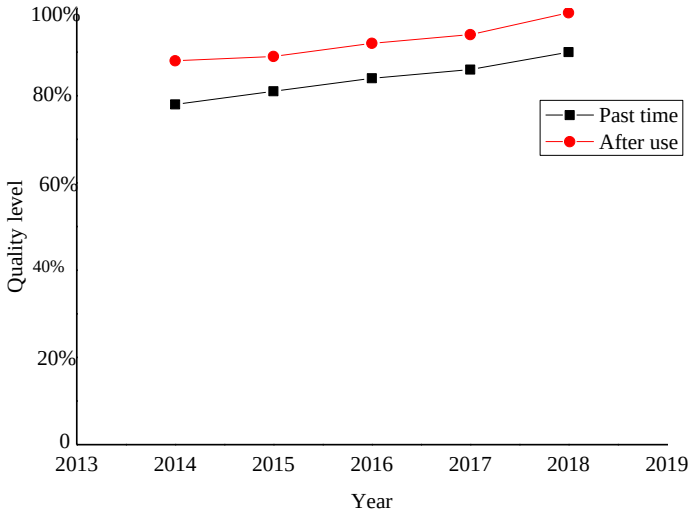

Figure 7. The effect of CAD/CAM technology on improving quality

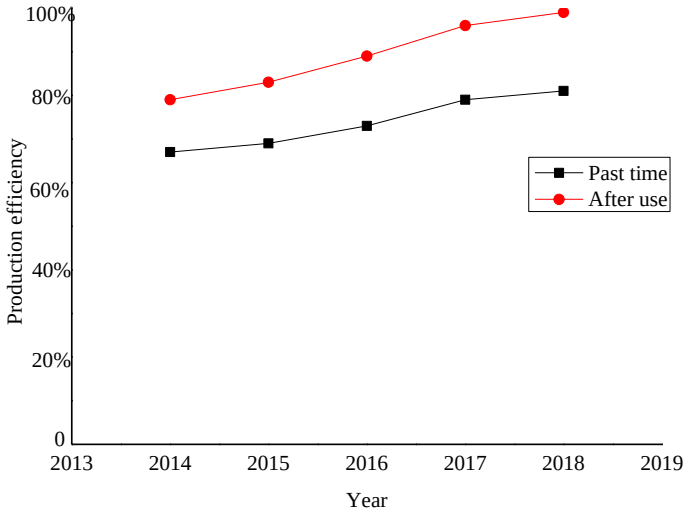

Figure 8. The effect of CAD/CAM technology on improving productivity

The function application of the pipe cutting design system and the pipe cutting machine NC system was analyzed. The results showed that the combination of CAD/CAM technology was an important way to realize the jacket cutting production. From the graphic information and non-graphic information input of the single piece structure to the automatic drawing of the pipe cutting diagram, the intersecting line calculation was conducted in the whole process. The final processing data was generated by referring to the process requirements, and the final data was input into the NC cutting system as the basic parameter data. Automatic machine cutting was realized through automatic NC programming, NC machining simulation, pipe fitting cutting, and pipe fitting size inspection. The two systems of CAD/CAM were organically combined to meet the production requirements of the complete process. Figure 9 shows the CAD/CAM match type for the complete process flow from design to machining.

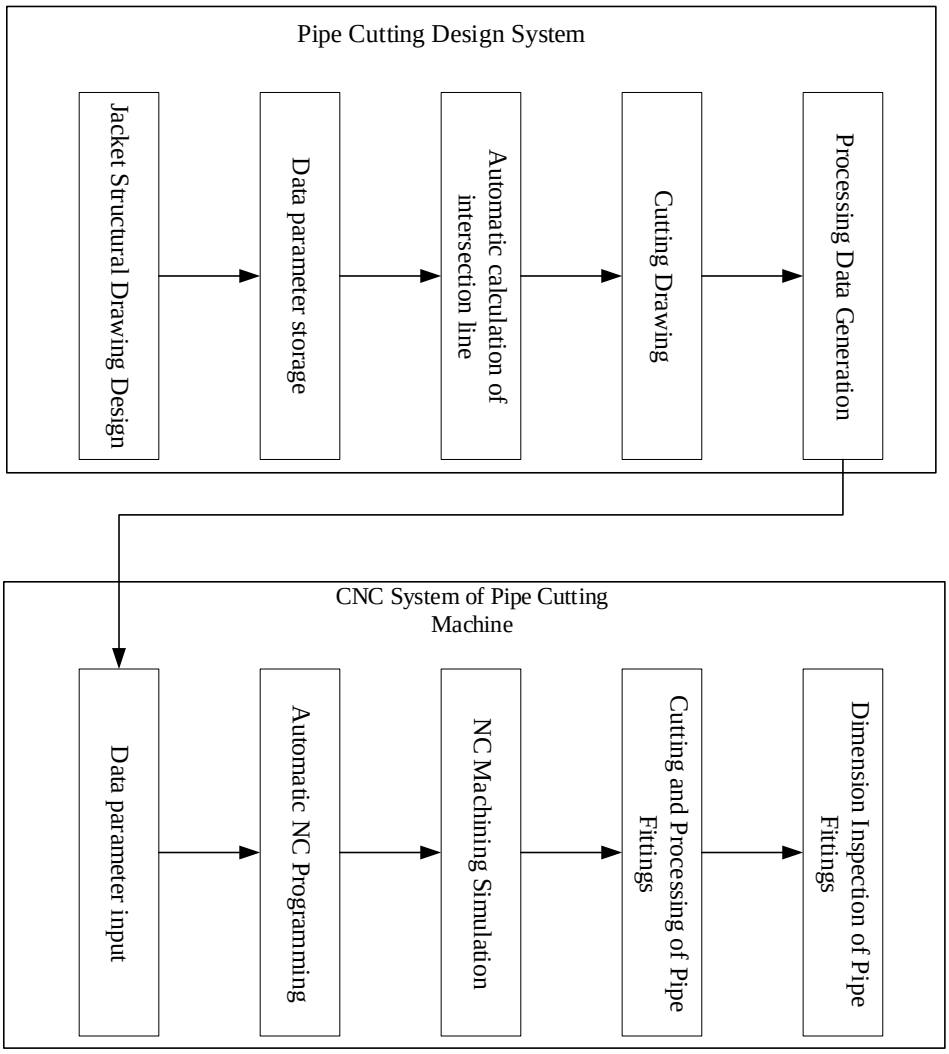

Figure 9. The combination of pipe fitting cutting design system and pipe cutting machine NC

4. CONCLUSION

In this study, relevant technologies of CAD/CAM system for jacket construction were introduced, and the simulation results showed that the system had a good operability in offshore jacket construction, which could meet various requirements in the design and manufacture of jacket fittings and effectively improve the production efficiency. CAD system and CAM system have been used organically since the beginning of system design to reduce the waste of resources, optimize the allocation, realize the functional requirements of the complete technological process from design to processing, automate the design and manufacturing, reduce the working intensity of personnel, reduce the processing time of pipe supports, and improve the construction technology and efficiency. In the face of increasingly complex requirements on production requirements during the construction of jacket, further improvement of system integration level and expansion of system functions can be considered. In the subsequent optimization design, better intelligent manufacturing can be achieved by artificial intelligence technology.

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