Special equipment for processing inner holes in bending section of the main pipeline in nuclear power plant

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Abstract: Because of the special forging material and complex pipe structure of the main pipe of the AP1000 nuclear power plant, a single general equipment can not meet the requirements of machining the inner hole of the bending section. At present, most of them adopt the method of approaching theoretical dimension by manual grinding, which makes the labor intensity of workers large, the work cycle is long, and it is difficult to ensure the machining accuracy of the workpiece. In view of the practical difficulties in processing the elbow inner hole of nuclear power main pipeline, the copying processing equipment is designed. The fixed circular arc guide rail is used in the equipment. The arc curvature of the guide rail is the same as that of the workpiece. The boring cutter head moves axially along the fixed circular arc curvature guide rail for copying boring. After testing, it fully meets the requirements of the shape, position and size accuracy of the inner hole in the bending section of the nuclear main pipeline. The method is efficient, accurate and innovative, and provides reference for similar product processing schemes.

1 Preface*

The AP1000 is the third-generation nuclear power technology developed by Westinghouse and EPR developed in France. It is introduced in our country to meet the electricity demand for the power, vigorously develop nuclear power technology and make China's nuclear power technology develop rapidly and established a national nuclear power technology company, it is responsible for promoting the introduction, digestion, absorption, innovation and leap-forward development of AP1000 third-generation nuclear power plant technology [1].

The main pipeline used in AP1000 nuclear power plant is a thick-walled pressure pipeline connecting reactor pressure vessel and steam generator, it is the ‘main artery’ of the nuclear steam supply system to output nuclear reactor core heat energy, and one of the key nuclear equipment of pressurised water reactor nuclear power plant [2]. It is made from forged stainless steel by ultra-low carbon-nitrogen controlled with high strength. The pipe is composed of two straight pipes at both ends and a section of elbow pipe. It is a large aperture ratio and bending angle, and very difficult to make.

The main pipeline was manufactured by IBF in Italy, the company keeps its manufacturing technology a closely guarded secret and only provides their finished products, the price is almost unacceptably expensive. Even its partner, Westinghouse, was only able to select and view the drawings of the AP1000's main pipeline.

To break through the technical blockade, reduce the cost of nuclear power construction in China and remove the technical barriers in the process of the nuclear industry localisation, Four key enterprises in the machinery industry are organised to be a new co-development and co-production complex by the National Nuclear Power Technology Corporation to develop the localisation process of AP1000 main pipeline, they are China First Heavy Industries, China Second Heavy Industries, Shanghai Heavy Industries and Bohai Ship Heavy Industries. The AP1000 main pipeline research and development project has been included in the major national science and technology special equipment manufacturing projects, and a research group consisting of the four members was established [3].

2 Processing method producing bending section of main pipeline in our country

2.1 Technical parameter of AP1000 main pipeline in nuclear power plant

AP1000 nuclear power plant's main pipeline system consists of two loops, each of which consists of two hot section tubes and four cold section tubes [4]. The hot section of the main nuclear power plant pipeline is the most difficult part to manufacture in the main pipeline system shown in Fig. 1. Its outer diameter of the main pipeline is 952 mm, the inner diameter is 787 mm, and the bending angle is 56.4° ± 0.1°. The finished part is tested according to the quality inspection specification of heat pipe forgings of AP1000 sa-376tp316ln [5].

2.2 Present method of processing inner hole in bending section

2.2.1 Grinding method: According to the French RCCM-M standard, the initial machining method of the inner hole in a nuclear system elbow is the grinding method to ensure the quality of the main pipe, a certain margin must be cut in the internal and external circles, it is around 20 mm based on the actual situation of the blank [6]. When machining the bending outside surface of elbow, it is usual to use general processing equipment with a certain amount of grinding allowance. Or the grinding method has to be used to cut the allowance. The way is that the inner and outer circle diameters warp and weft grid lines are drawn and marked with the outer circle of the elbow as the datum of drawing lines, then measure the wall thickness at the intersection of the inner and outer circles of the elbow with special measuring tools and instruments, and fill data in the table. Based on them then calculate the difference between the measured values and the theoretical wall thickness, and assign points of the inner and outer circles to be ground out, and fill data in the table again. Then, drill out the grinding base hole depth with a hand electric drill and leave the allowance value depending on the data of the table; grind the inner and outer circles according to the base hole, compare with the rough grinding samples. Repeat the above step until we meet the drawing requirements with the fine grinding sample.
material surface could cause discolouration due to overheating. Finally, unless approved by the buyer, the grinding material only use silicon carbide (commonly known as emery) or alumina, in which case the grinding efficiency is low and the processing cycle is long.

2.2.2 Other special processing equipment: The utility model patent named an AP1000 nuclear power plant technology primary circuit main pipe elbow hole finishing equipment applied by Yantai Haimanur Nuclear Power Equipment Co., Ltd [7]. A mechanical sliding seat (10) equipped with Column (1) that can slide horizontally along the mechanical slide seat (10) is installed on the bed (9); and the straight boring bar (2) its central axis is parallel to the working surface of the bed (9) and the workbench bed (6); a sliding slide seat (5) for mounting workpieces is installed on the table bed (6); and the front end of the straight boring bar (2) is hinged with boring power head (4) (power motor). Through the three-axis linkage control, the cutting plane of the power head cutter tip in boring is always along the radial direction of the arc of the elbow, and the fixed angle cutting can be realised finally (Fig. 2).

The advantage of this method is that the processing of AP1000 nuclear power plant's main pipe deep-hole elbow by special machine tool is realised initially, but there are some shortcomings. First, because of the influence of the turning radius (4 power motor length) of the boring head, the curved surface of the elbow section can be simulated approximately, and could not process the precise profile of the elbow section, and the processing of the transition section between the arc and the straight line at the outlet end could not be realised. Secondly, the total stiffness of the equipment is weak because of the hinged and the overhanging boring bars is long; Lastly, the product structure is relatively complex, the equipment is heavier and bulky according to the layout.

2.2.3 AP1000 nuclear power plant's main pipeline processing and polishing complete equipment [8]: The equipment is a project jointly declared and developed by Sichuan Yibin Push Group Co., Ltd., Sichuan Dual Group (Deyang) Heavy Equipment Co., Ltd. and Xi'an Ruite Rapid Manufacturing Engineering Research Co., Ltd. [9].

The equipment is used with the Longmen Machining Center. The principle is that after generating the three-dimensional model and spatial coordinates of the work-blank of the main pipe on the special tooling are generated with the ‘laser scanning in place detection technology’, calculate the optimal machining allowance by comparing with the theoretical model, then locate the theoretical centreline of the hole diameter. Through numerical control (NC) system control, multi-axis linkage interpolation between the machine tool and special equipment for follow-up processing, the real-time position of X, Y, Z and W axes of the machine tool is automatically measured for rotating joint axes B1, B2 and B3, and the machine following the centreline of the main pipeline. The rotating axes at joints make the tool always process the inner wall according to the centreline of the main pipeline, to make the design benchmark and the theoretical basis of the inner hole of the main pipeline the same. Based on the processing is exactly the same. According to the processing conditions of parts, the NC system should realise seven-axis four linkage. The follow-up processing device is shown in Fig. 3 [9].

In Fig. 3, the counterweight 1 mainly balances unidirectional overturning moment brought by the sleeper on the gantry 2, to avoid the deformation of the sleeper caused by the overturning moment; bar arm 3, rotating joints 4 and large torque motors 5 and cutter discs are the core components of the servo device, using three rotating axes B1, B2 and B3 to realise the arc trajectory (the total rotation angle of the movable joint is larger than the bending angle of the whole pipeline). The gantry machine tool realises feeding.

The main features of this device are the flexible structure, many functions, high technical difficulty and expensive. Firstly, we need to develop a high stiffness and no clearance rotating joint; secondly, the multi-axis interpolation software and visual contrast

Though the above-mentioned method seems simple, it is very hard to operate. Reasons are as follows.

First, the space in the elbow pipe is too small to operate; secondly, the working environment is very bad; thirdly, the material of the main pipe is a special stainless steel, whose grinding performance is poor and the operating efficiency is very low, and the grinding wheel is easy to be stuck. If the grinding force is too large or the continuous grinding time too long, the
The boring cutter disc is the core component of the imitation processing equipment which feeds along the curve rectangular guide rail with rack-and-pinion meshing. The servo motor reduces the speed through the worm wheel reducer, to drive the cutting. To improve the machining efficiency and the cutting force, the multi-tool servo motors, mesh with the double gears, to drive the cutting tool spiral cutting by double servo motors, which has better boring rigidity, higher machining efficiency and lower product input cost.

3 Conclusion
Comparing the structures of the above three special equipment, the imitation processing equipment adopts multi-cutter boring, integral rectangular guide rail, and the structure of adaptive follow-up support device to design and develop excellent products suitable for solving the processing problems of AP1000 nuclear power plant's main pipeline and shorten its production cycle. The above scheme is also tried to be used in other fields, such as: curved tunnel, oil, natural gas, shale gas exploitation, etc., to provide a reference for similar product processing schemes.

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