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Development of remote pipe cutting and welding tool for divertor cassettes in JT-60SA

JT-60SAダイバータカセット配管用遠隔切断および溶接装置の開発

T. Hayashi, S. Sakurai, K. Shibanuma and A. Sakasai
林 孝夫, 櫻井 真治, 柴沼 清, 逆井 章

Japan Atomic Energy Agency
801-1 Mukouyama Naka Ibaraki 311-0193, Japan
日本原子力研究開発機構 〒311-0193 茨城県那珂市向山801-1

Remote handling (RH) system is necessary for the maintenance and repair of the divertor cassette in JT-60SA. Because the space around the cooling pipe connected with the divertor cassette is very limited, the cooling pipe is to be remotely cut and welded from inside for the maintenance. Remote pipe cutting and welding tools accessing from inside pipe has been newly developed for JT-60SA. The tool head equips a disk-shaped cutter blade and four rollers which are subjected to the reaction force. The tool pushes out the cutter blade by decreasing the distance between two cams. The tool cuts a cooling pipe by both pushing out the cutter blade and rotating the tool head itself. A laser welding method was employed to perform circumferential welding by rotating the focusing mirror inside the pipe. We have achieved robust welding for a large gap up to 0.5 mm as well as the maximum angular misalignment of 0.5˚ between connecting pipes by using this newly developed tool.

1. General

JT-60SA (JT-60 Super Advanced) with fully superconducting magnets is now being manufactured as a combined project of the Japanese national project toward DEMO reactor and a satellite tokamak project for ITER in a broader approach with Japan and EU collaboration[1,2]. One of the features of JT-60SA is its high power (41 MW) long pulse (100 s) heating at the final stage, causing the large annual neutron fluence of 1.5×10^{21} neutrons/year. The expected dose rate at the vacuum vessel may exceed 0.1 mSv/hr, the human access inside the vacuum vessel is restricted. This indicates a remote handling (RH) system is necessary for the maintenance and repair of the divertor cassettes [3].

Cooling water pipes, which connect between the divertor cassette and the vacuum vessel with bellows in the outboard side, are required to be cut and welded inside the vacuum vessel. Because the space around the cooling pipe is very limited, the cooling pipe is to be remotely cut and welded from inside for the maintenance.

2. Cooling water pipe joints

The outer diameter, thickness and material of the cooling pipe are 59.8 mm, 2.8 mm and SUS316L, respectively. The cutting and welding position is at about 500 mm depth from the mounting surface on the divertor cassette frame. After butt welding of pipes, an upper plug is required to be lap welded [4].

3. Pipe cutting tool

A cutting tool has two AC motors and two driving shafts in order to push out the cutter blade and the reactive force receiving rollers, and to rotate the tool head itself. The cutting head is mounted to a linear motion guide in order to move vertically and to access the pipe joint. The cutting head equips a disk-shaped cutter blade on the cutter holder and four reactive force receiving rollers on the roller holder. The screw-shaft pushes the cutter and roller holders outward in the radius direction of the tool by decreasing the distance between two cams.

Each member of the tool head is positioned in a casing having an outer diameter of ϕ44 mm. Because the narrowest diameter for accessing the pipe joint is 45 mm, the clearance between the smallest inner diameter of the pipe and the tool is 1 mm in the radius direction, consequently being able to insert the tool head.

External threads of M12 × P1.0 are created on the central shaft, i.e. left-handed and right-handed threads are formed on the base and distal end sides, respectively. Internal threads are also created inside both cams in opposite directions. When the screw shaft is rotated clockwise, both cams move inside, and the taper part of the cam pushes the cutter and roller holders in the radius direction.

The range of motion of two cams and the cutter blade are all 10.8 mm, because the tilt angle of the cam to push out the cutter blade is 45 degrees. The tool head is able to push the cutter blade up to

32.5 mm in radius, i.e. 65 mm in diameter, which is enough to cut the pipe having an outer diameter of 59.8 mm [4]. The cutter blade is provided as a unit with the cutter shaft in the cutter holder, which enables easy replacement when being worn. Thus, the cutter blade can be removed from the cutter holder without disassembling the head.

4. Pipe welding tool

A pipe welding tool equips a linear motion mechanism to insert the head vertically such as pipe cutting tool. The tool also equips a rotation mechanism to perform the circumferential welding. In this paper, a simple frame is used for welding test instead of the divertor cassette frame.

A laser welding method was employed to perform circumferential welding by rotating the focusing mirror inside the pipe. Laser beam focused Φ1.2 mm at the groove. This laser spot radius is optimized to reduce sputtering as well as to obtain proper penetration depth. The outer diameter of the welding tool head is 36mm. The tool head equips a tilt mechanism like a pendulum operated by pressed air. The tool is pushed to the opposite side of the laser emission and kept in contact with the inner surface of the upper pipe through two balls. Thus, the distance between the welding head and the groove is maintained constant during the welding, which is conductive to good positioning accuracy of the laser beam.

In JT-60SA, the welding tool need to provide the flexibility and adaptability for the groove with a gap, an angular and an axial misalignments. In general, laser welding requires narrower gap than other welding methods. If there is a large gap at the groove, a filler wire is generally supplied to a weld puddle. However, there is no space around the welding tool head for the mechanism to supply the filler wire, because the welding is carried out from inside of the pipe. Therefore, instead of the filler wire, a jut is proposed on the inner side at the end of the upper pipe connected with the replaceable divertor cassette in order to enlarge the allowable gap. The width and height of the jut are 3 mm and 0.5 mm, respectively. Because the volume of the jut almost corresponds to that of the gap of 0.5 mm, the edge jut of upper pipe can enlarge the allowable gap up to 0.5 mm by filling the gap with welded jut.

In the case of replacing the divertor target, the lower pipe is required to be re-welded after cut by a disk-shaped blade [4]. Therefore, the jut have to be created on the new upper pipe, which can apply to both types (virgin and cut) of lower pipes. The angle of end of the upper pipe machined to 10.8˚ also in order to fit the pipe cut by the disk blade. The incident angle of 15˚ and the position of the laser beam are determined so as to melt both the inner jut and the outer burr of the pipes. Therefore, the positioning of the laser beam at the edge of the upper pipe is the most critical control issues for a robust welding.

If the position of laser beam is sifted from the target of groove, a robust welding cannot be realized. Desired positioning accuracy of the laser beam is required to be less than ±0.1mm in any misalignment. Because the edge jut is created on the upper pipe, the laser beam is irradiated along the edge of the upper pipe to fulfill the gap by melted jut. A position control mechanism in harmony with the welding rotation is introduced.

Positioning accuracy of the laser beam is realized to be less than ±0.1 mm along the circumferential target by a position control mechanism even in the case of up to an angular misalignment of 0.5˚. It is notable that we have achieved robust welding for a large gap up to 0.5 mm as well as the maximum angular misalignment of 0.5˚ between connecting pipes by using this newly developed tool [5].

References

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