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Applications of Underwater Laser Peening in Nuclear Power Plant Maintenance

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Abstract

Stress corrosion cracking is the major threat to the safe and stable operation of nuclear power plants, and the residual tensile stress is one of its major causes. For in-service nuclear power plants, the most effective means to prevent stress corrosion cracking is change the stress status of material surface by peening technology. Compared with traditional shot peening, laser peening has advantages of good directionality, good accessibility,easy to control ,no residue ,deeper compressed layer ,and more suited to use in the maintenance of in-service nuclear power plants. In this paper, research and application of underwater laser peening technology in nuclear power plant maintenance are summarized.

Keywords: Nuclear power; in-service maintenance;laser peening;underwater

1. Introduction

There are more than 400 nuclear power plants in the world. It is a very important issue to operate them safely and stably. Stress corrosion cracking(SCC)is the major factor to reduce the reliability of aged reactor components, which may cause unscheduled outages and reduce availability. Initiation and propagation of SCC due to three factors, which must be present simultaneously: metallurgical susceptibility, critical environment,and static(or sustained) tensile stresses. For nuclear power plant, with the special environment and material,the factor that contributes SCC is primarily the residual tensile stress induced by the welding processes[1]. Mitigate or eliminate stress corrosion and SCC is the effective means to ensure nuclear power plants operating safely and stably. How to strengthen weak parts of in service

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nuclear power plants to achieve the effective maintenance is an very worthy of concern for both economic and social benefits.

2. Advantages of laser peening

With the advantages of good directionality,easy to transport and high energy density, the laser has an important value in the maintenance of nuclear power plants, underwater laser peening is one of the major applications.

Laser peening is an emerging surface-treatment technology which was developed in the 1970s at Battelle Columbus Laboratories,It has made a significant strengthen effect when used in aviation component, and has showed potential in the device life extension, this lay a foundation for its application in the nuclear power plants.

References[2]present the principle of laser peening .Compared with other peening technology,the implementation of laser peening does not produce a rebound medium and the reaction force, and enables precise remote control, therefore, it does not exist residue that affect the normal operation, and can achieve the complete operation at some narrow or special shape area . A more crucial point is that the effect of laser peening has much more merit than the ordinary means, the depth of compressive stress layer up to 4mm or more with the surface roughness of the components unchanged. Laser peening has more than two times effect on improve fatigue performance of stainless steel than conventional shot peening, therefore, it is particularly suitable for the life extension maintenance of nuclear power plant.

3. Present research and application status

In the mid-1990s,Toshiba began their research on laser peening. In 2002,they accomplished laser peening treatment in BWRs by using laser transmitter system which transmitted 10 MW laser pulses through 50 m optical fiber. Fig.1 illustrates the systems applied to BWRs[3].

In recent years,to enhance the usability and reliability of the laser peening system,Toshiba integrated an ultra-compact laser unit into the system named"Portable Laser Peening(PLP)systems"showed in Fig.2. A prototype of the portable laser peening(PLP)system has been developed as shown in Fig.3,where the system is set on a control rod drive(CRD)housing in a BWR. A waterproof laser unit,a positioning unit and an irradiation head are integrated into an underwater device.Fig.4 illustrates the concept applying the system to the weld of a stub tube for a control rod drive(CRD)housing in a BWR.

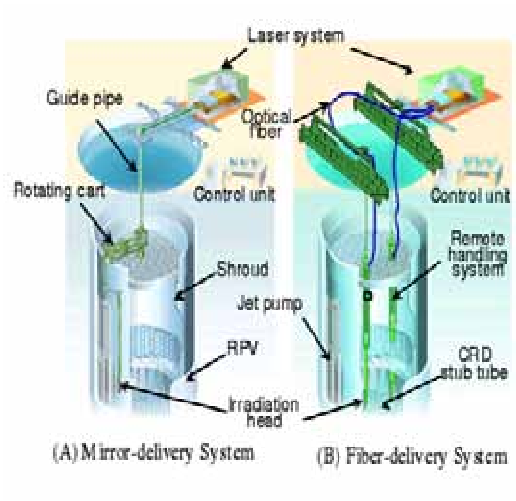

Fig.1 Laser peening systems for BWRs

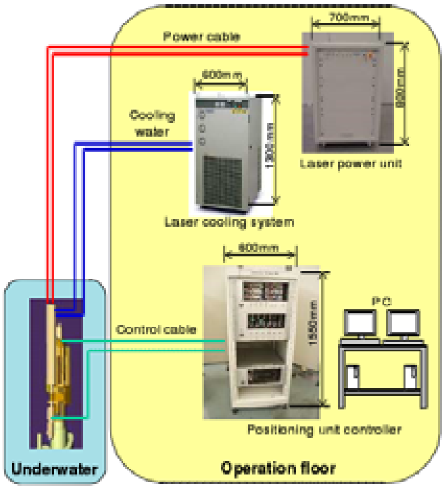

Fig.2 Compositions of PLP system

Fig.3 Prototype portable laser peening(PLP) system for BWRs

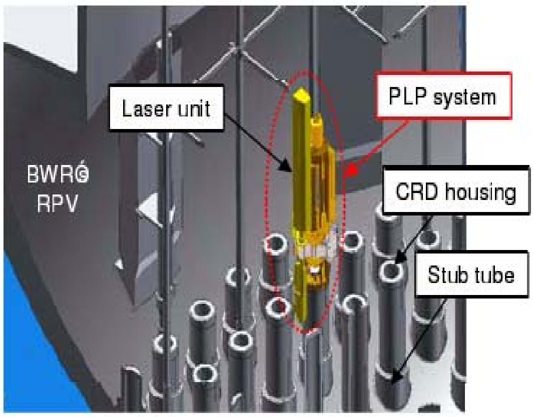

Fig.4 Concept of portable laser peening(PLP)system

For the outer surface of bottom mounted instrumentation (BMI) nozzles and J-groove welds,they developed a special device as shown in Fig.5 and Fig 6,this device can control 6-motions and can trace laser beam on operating position accurately. Fig.7 shows the photo of the FLP operation in Ikata Unit 2.

For primary water inlet nozzles,they peened the inner surface of the dissimilar metal welding,which is of nickel base alloy,joining a safe end and a low alloy metal nozzle.Fig.8 shows the FLP device and the area to be peened.The FLP device has two irradiation heads,it was set into one nozzle and two irradiation heads were traversed axially across the weld and can treat two portions simultaneously to reduce the opetration time. Fig.9 shows the photo of the FLP device. After the peening treatment, FLP device was rotated and treated another nozzle.

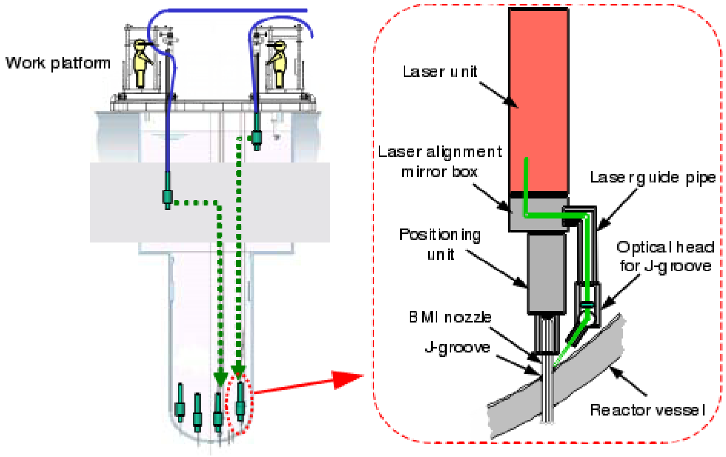

Fig.5 PLP system for J-groove welds of BMI nozzle

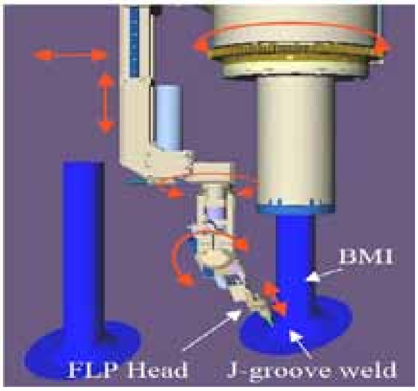

Fig.6 FLP device for J-groove welds of BMI

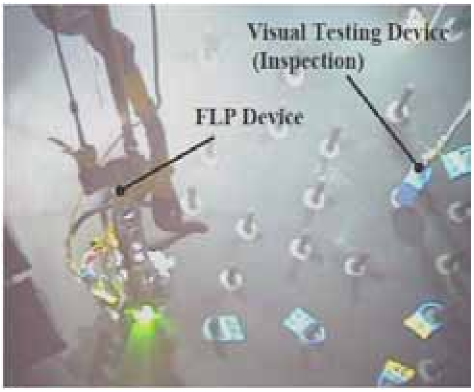

Fig.7 Photo of FLP device for J-groove welds of BMI

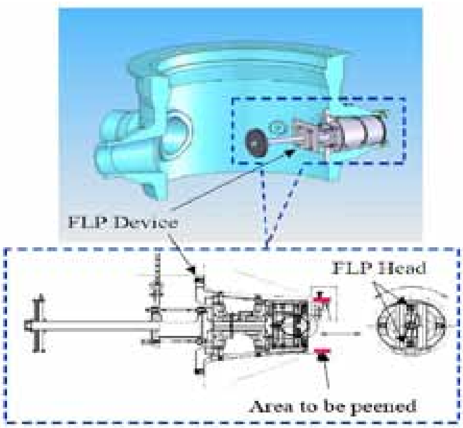

Fig.8 FLP device for primary water inlet nozzles

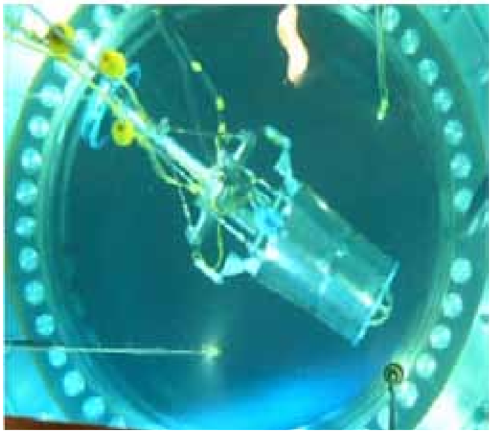

Fig.9 Photo of FLP device for primary water inlet nozzles

For the preventive maintenance against primary water stress corrosion cracking (PWSCC),they have applied FLP system for Ikata unit 1 and unit 2 from December 2004 to January 2006 as the first case in the world for PWR power plants. They treated the inner surface and J-groove weld of BMI nozzles,the core deluge line nozzle welds and the primary water inlet nozzle welds, the operation was successfully completed within the scheduled date with no trouble. This result shows the reliability and the applicability of FLP system for PWR power plants[4]. In 2009,Toshiba Corporation has developed a multifunction laser welding head as shown in Fig.10 and Fig.11,The size of the developed head is height of approx.85mm,width of approx.85mm,and depth of approx.45mm.Owing to the compactness of the developed head,it is possible to access to narrow areas in the reactor components.The head is able to perform not only underwater laser peening as preventive maintenance,but also laser welding as repair and laser ultrasonic testing as inspection[5]. As of 2009, by using laser peening technology, Toshiba had eight nuclear power plant equipment maintenances.This technology also has been recognized by the relevant departments of U.S., Electric Power Research Institute(EPRI) has launched the substantial cooperation with Toshiba , and they want apply the laser peening technology for nuclear power stations in the U.S.

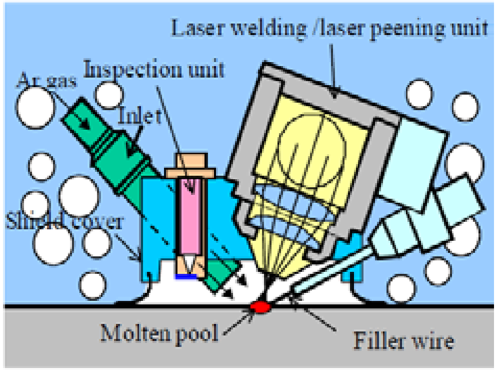

Fig.10 Schematic of multifunction laser welding head

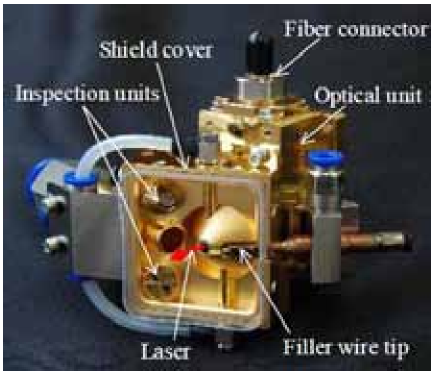

Fig.11 Photo of multifunction laser welding head

In France, extensive work was carried out since 1986 on all the fields relevant to laser peening,including physics of laser-induced shock waves,FEM simulation of residual stresses induced by the laser peening process,fatigue behavior of aluminum alloys treated by short laser pulses,corrosion resistance of laser-peened stainless steels,and improvement of materials properties such as fatigue, corrosion or wear[6].

In U.S., Lawrence Livermore National Laboratory in University of California examines the effects of laser peening on Alloy 22(UNS N06022),which is the proposed material for use as the outer layer on the spent-fuel nuclear waste canisters to be stored at Yucca Mountain.The results of laser-peening experiments shows that the depth of compressive residual stress have a significant dependence on the number of peening layers and a slight dependence on the level of irradiance,and laser peening can produced compressive residual stresses to a depth of 4.3mm in the 33mm thick weld at the center of the weld bead where high levels of tensile stress were initially present[7].

China's laser peening technology began in about 1990,it is a later start but the rapid development,and the study mostly focused on aviation components laser peening treatment. Wu Shu-hui and his colleagues in Suzhou Nuclear Power Research Institute discussed the laser peening applications in nuclear power environment, their point is that the laser peening is particularly suitable technology for maintenance of equipment life extension of nuclear power. They proposed the difference of laser peening technology between used in nuclear power plant and in other areas, and the current technical breakthrough was also discussed, which including laser peening treatment of nuclear power equipment, laser propagation in different media and evaluation of the effect of laser peening[8][9].

4. Conclusions

With the nuclear power plants gradually reached their design operation life, in-service preventive maintenance and life extension work of aged nuclear power plant has been put on the agenda. Because of its many inherent advantages, after further technical improvement,laser peening will become one of the important technologies for underwater in-service maintenance.

Acknowledgements

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