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Laser applications in nuclear power plants

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Abstract. This paper reports the state of the art of using a solid-state Nd:YAG laser for material processing applications such as cutting, welding and drilling of several components of operational nuclear reactors in radioactive environment. We have demonstrated several advantages of laser-based material processing over conventional methods, and these are discussed briefly. At NPCIL, we have used laser techniques to cut stainless steel sheets up to 14 mm thickness and stainless steel weld up to a depth of 3 mm. This remotely operable laser system has been engineered for its robustness with proper fixtures and tooling for various material processing operations on industrial scale.

Keywords. Nd:YAG laser; fibre-optic beam delivery; laser cutting; laser welding; nuclear reactor.

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1. Introduction

The use of solid-state Nd:YAG laser with fibre-optic beam delivery system to material processing applications has several advantages over conventional methods. It has been found to be extremely useful for applications such as cutting, welding and drilling in radioactive environment, reasons being easiness in tool handling, flexibility, non-contact nature, longer tool life, remote operation capability and thus low MANREM consumption, rapid processing and economic viability. Laser material processing in nuclear power plant is mainly concerned with:

(1) Removal of nuclear power reactor components by laser cutting
(2) Joining of materials and sealing by laser welding
(3) Decontamination and decommissioning of nuclear power reactor

Laser material processing is a thermal process, in which the material absorbs laser beam energy to attain melting temperature and a high-pressure gas is used to blow away the molten material. Energy per unit volume required to melt a given material depends on the material characteristics. It has been recognized that solid-state Nd:YAG laser can potentially address several applications on cutting and deep penetration welding of thin and thick stainless steel, along with decommissioning and decontamination in nuclear environment. However, these applications can be addressed only with multi-kilowatt power level lasers. In this article, a brief overview of the constructed flash lamps pumped Nd-YAG laser and also some specific material processing applications undertaken in different nuclear power plants of India using this laser have been presented.

2. Overview of the constructed Nd:YAG laser

An in-house (RRCAT, Indore) built flash lamp-pumped pulsed Nd:YAG laser (emitting on 1064 nm) has been used, along with beam delivery through optical fibre, for material processing applications [1]. The basic lamp-pumped Nd:YAG laser consists of a pump cavity containing a flash lamp and an Nd:YAG rod within a gold-coated elliptical reflector or a close coupled diffuse reflector and an optical resonator suitably designed to achieve high output power and better beam quality. Since most of the electrical input is dissipated as heat, the wall-plug efficiency of the laser system is limited to ∼3–4% and beam quality is also limited by strong thermal lensing and stress-induced birefringence. In order to enhance quality and range of material processing applications, higher power Nd:YAG lasers with improved beam quality and beam delivery through optical fibres having smaller core diameter are necessary, and these are being developed for specific applications. Over the last two decades, these have been proved to be the most appropriate system in harsh radioactive environmental conditions of nuclear power plants [2].

Figure 1 shows a typical view of an industrial Nd:YAG laser developed at SSLD, RRCAT for material processing applications in nuclear reactors of Nuclear Power Corporation of India Ltd. (NPCIL).

3. Applications of laser in NPCIL

With the help of RRCAT, we have carried out a number of material processing jobs in nuclear power plants of NPCIL, India, by invoking different innovative techniques

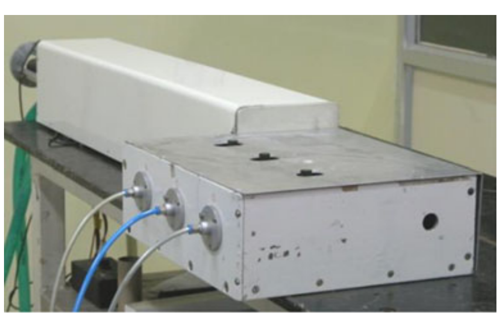

Figure 1. Industrial Nd:YAG laser.

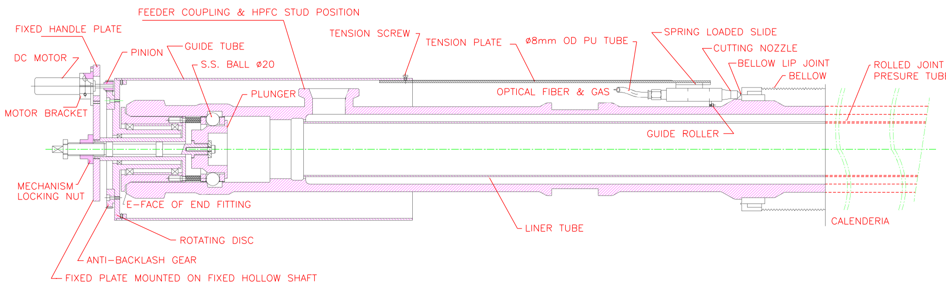

Figure 2. A sketch of the bellow lip cutting fixture mounted on the E-face of the coolant channel.

with the industrial Nd:YAG laser system. Some of the important applications are briefly described below:

(1) Bellow lip cutting and High Pressure Feeder Coupling Stud (HPFC) cutting during the En-masse Coolant Channel Replacement (EMCCR) campaign at Narora Atomic Power Station Reactor #1 in May 2006.
(2) Cutting of pressure tubes from Madras Atomic Power Station#1 (MAPS#1) in April 2005.
(3) *In-situ* cutting of the selected coolant channel S-7 at Kakrapar Atomic Power Station (KAPS#2) (cutting of 12 mm thick end fitting and 4 mm thick liner tube of stainless steel from inside) in January 2005.
(4) Cutting of the end plates of Pressurized Heavy Water Reactor (PHWR) fuel bundles in hot cell in Bhabha Atomic Research Centre (BARC).
(5) Development of a miniature cutting mechanism for steam generator tubes (14 mm ID) from inside.
(6) *In-situ* bellow repair for secondary shut down system developed and qualified on mock-up.

Also, the laser system has shown its great potential in removing single channel from KAPS reactor. It was found to be extremely difficult to cut the reactor end fitting using mechanical means as space restriction prohibited usage of a conventional cutting tool. Although single-point mechanical cutters could possibly be utilized for this operation, these mechanical cutters are bulky, require frequent replacement and time consuming resulting in higher MANREM expenditure. The laser, on the other hand, is found to be very effective even in such constrained space to cut liner tube and then the end fitting. This called for grooving at the welding point up to the depth of welding (∼3–4 mm) and then pulling the channel [3].

Figure 3. Fixture for cutting of coolant channel.

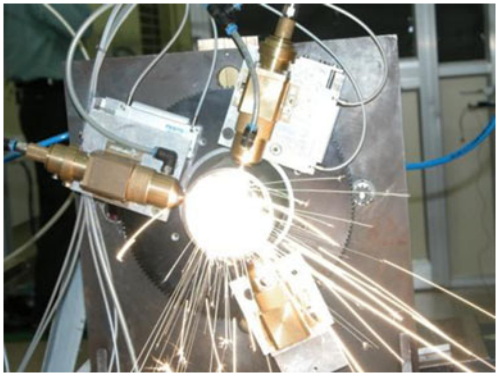

Figure 4. A mock-up of laser cutting pressure tubes.

The mechanism for laser cutting of bellow lip developed at RRCAT consists of a motorized circumferential rotary arrangement, which can be mounted on the end-face (E-face) of the coolant channel and can be fixed on it by tightening a single bolt. The tool is designed to fit on the E-face of the end fitting using bore of the end fitting. Tightening of a box nut of size M32×2.5 can lock the fixture on the E-face. This fixture is accompanied by an arm, which holds the laser cutting head and nozzle. For accurate positioning of the laser-cutting nozzle, it is guided by three bearings touching the end-fitting surface before the neck position of the bellow lip. Figure 2 shows a sectional view of the bellow lip cutting fixture mounted on the E-face of the coolant channel.

Two industrial Nd:YAG lasers with four port time shared fibre-optic beam delivery and 150 m long fibre-optic cable were deployed for cutting of the bellow lip of the coolant channels, one each on the north and south vaults of NAPS#1 -220 MW reactor and *in-situ* bellow lip cutting was performed and separation was ensured for all the 612 bellow lips. The fixing of tool on any of the coolant channels required about 1 min and the cutting process took 10 min for each bellow lip, and total operation was completed within a few days of laser operation. Laser cutting of 50 high pressure feeder coupling studs (16 mm MS bolt) was also performed within an hour of laser operation. This resulted in a large

Figure 5. A cutting head inserted through the SG tube and the cut sample.

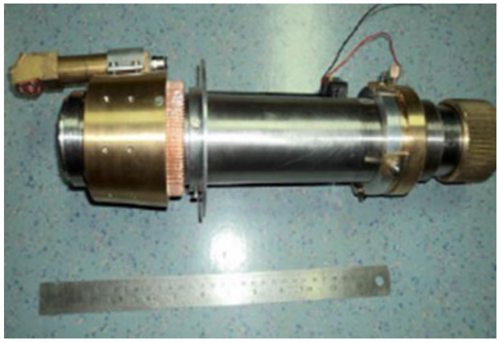

Figure 6. Manipulator with laser attachment for welding *in-situ* for repair.

MANREM saving as compared to conventional technique and also time saving of at least two months leading to enormous cost saving.

Kakrapar Atomic Power Station#2 was the first reactor which used Zr–2.5% Nb pressure tubes and it was required to generate data on these kinds of pressure tubes. It was decided to cut and remove one of the pressure tubes after about eight years of reactor operation. To extract the pressure tube, it was required to cut liner tube and end fitting from inside due to space restrictions. This was possible by using laser to remotely cut the fixture specially designed for this coolant channel. The coolant tube cutting fixture developed is described briefly here. The tool fixing mechanism consisted of two disks

Figure 7. Laser cutting in progress to separate the retainer nut sleeve from the upper stand pipe of secondary shut-down system mock-up made at the R&D Centre, Tarapur.

Figure 8. View of the end ring weld from inside before repair.

of aluminium, one is attached at the E-face and the other disk is inserted inside the end fitting through a dual rod handle which comes out from two diametrically opposite holes in the first disk and holds the two disks together and can also fix the separation of the two disks. Figure 3 shows the developed fixture [4].

Pressure tubes in PHWRs are about 5 m in length and are highly radioactive. After EMCCR operations, these tubes are stored as such which require a large space. For initial study, a laser-based cutting fixture was designed and deployed for cutting seven pressure tubes removed from MAPS#1 in two halves to reduce storage space [5]. This laser-based cutting fixture was found to be very useful in reducing storage space. This will be further deployed in mass cutting of pressure tubes by slotting them linearly in three pieces using three nozzles simultaneously inclined at 120° with each other and then cutting it circumferentially after a certain length. Figure 4 shows a mock-up of pressure tube cutting mechanism. A miniature laser cutting head with 13.5 mm diameter was also developed for cutting or sampling of leaky steam generator (SG) tubes in nuclear power plants. Figure 5 shows the miniature cutting head inserted through the inconel SG tube and the cut sample from SG tube.

Development of tool specific to the application is often needed in nuclear applications, i.e., specific gadgets to reach specific location precisely. There was a requirement of sealing of secondary shutdown system as the bellow was not holding the pressure. *In-situ* repair was called for and was tried on mock-up for qualification at R&D Centre, Tarapur.

Figure 9. View of the end ring from inside after repair by fusing the weld bead.

Figure 6 shows the manipulator with laser attachment nozzle which takes the reference of secondary shut down system shut off tube for its mounting and then re-welding of cracks for repair.

There was a requirement for the removal of retainer nut sleeve from the upper pipe of the secondary shutdown system which was facing difficulty due to galling of material while cutting using grinding/single point cutting tool. The sleeve could be removed by laser cutting in mock-up as shown in figure 7.

The sealing of bellow assembly end ring was carried out using the same manipulator by fusing the weld beads on mock-up at the R&D centre. The views of the end ring weld before and after repair are shown in figures 8 and 9.

4. Conclusion

The enormous potential of the laser system has been realized in several applications in nuclear reactors ranging from thin and thick SS cutting and welding to large thickness concrete cutting in nuclear decommissioning. Material processing applications at nuclear reactors require miniature fixtures to hold and move cutting/welding nozzle in linear or circumferential direction with minimum tool installation time and physical effort. During the last few years, NPCIL could deploy laser system for many difficult applications. Efforts are underway in NPCIL and RRCAT to develop suitable laser-based operations for many critical applications such as cutting, welding and future decommissioning.

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