Laser Welding of Precision Engineering Components

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ABSTRACT

Laser beam welding (LBW) with its high power density produces narrow and deep welds with a small heat-affected zone. Nd-YAG laser has been used extensively in the fabrication of small precision components at Indira Gandhi Centre for Atomic Research (IGCAR). Some important laser welding works carried out are related to Eddy Current based Position Sensor (ECPS) and Sodium Leak Detector (SLD) in Diverse Safety Rod Drive Mechanism (DSRDM) of Prototype Fast Breeder Reactor (PFBR), and components for Ir-192 High Dose Rate (HDR) source for Board of Radiation and Isotope Technology (BRIT). ECPS is being designed to incorporate in the DSRDM to provide a measurement on signal which indicates that all the safety rods are dropped in case of a reactor scram signal. Mineral insulated (MI) cable of 1 mm diameter used as the eddy current coil in the ECPS has been terminated with suitable end configuration using laser welding. SLD is housed inside the electromagnet assembly of DSRDM to indicate if there is any leakage of sodium into the electromagnet. The fabrication of SLD requires precision laser welding of a few of its components. For the indigenous development of Ir-192 source assembly for use in HDR Branchy therapy, the feasibility study has been carried out for the fabrication of the miniature source holder by laser welding process. This paper discusses the techniques followed in the successful fabrication of above mentioned variety of intricate components used in critical applications.

Key words: Nd-YAG laser welding, precision components, PFBR, ECPS, DSRDM, sodium leak detector, HDR source

INTRODUCTION

Laser Beam Welding (LBW) is a high energy process that offers many advantages like deep and narrow weld, minimum distortion, heat affected zone of narrow width, excellent metallurgical quality, ability to weld small and thin components, increased travel speeds and non-contact welding [1]. For laser welding applications Nd-YAG and CO_2 laser are most commonly used. Nd-YAG (neodymium-yttrium aluminum garnet) laser uses a man-made crystal as its active medium and produces light with wavelength of 1.06 μm and CO_2 laser uses a mixture of gases including CO_2 as the active medium and produces light with wavelength of 10.6 μm.

Laser welding is a fusion welding technique achieved with very high power density obtained by focusing a laser beam to a very fine spot. To form a laser weld, the laser beam is brought to focus on or very near the surface of the work piece to be joined. In the first instance, a large percentage of the incident beam is reflected from the work surface for a minimum period of time [2]. However, the small amount of laser beam energy which is initially absorbed by the work quickly heats up the material surface, causing production of an energy absorbing ionized metal vapor, which rapidly accelerates the absorption of much of the energy that previously would have been reflected. This concentrated energy produces melting. The focusing lens of the laser system concentrates the beam energy into a focal spot as small as 100 μm diameter or less. At the work piece end, some shielding gas is usually applied to protect the weld from oxidization. Argon or helium is the most common choice. Argon is heavier than air so it provides a better shield than helium, but it ionizes easily and has much lower thermal conductivity than helium. This causes a problem with high power laser welding. With high powers, the metal vapor produced is partially ionized, with charged atoms and free electrons, and the free electrons absorb some of the laser light, reducing the power available for welding. As the vapor absorbs energy, it heats up, increasing the number of free elections and further increasing absorption. Helium shielding gas is more effective than argon in suppressing this effect because it cools the vapor plume and does not contribute many electrons itself.

Both pulsed and continuous wave (CW) lasers are used for welding. CW is used for speed while pulsing is used for precision. If the work-piece is thin, very high travel speeds are required to keep the heat input low if the laser is on continuous mode. Pulsing the beam allows more reasonable speeds be used.

Procedures adapted for the following three major laser-welding of critical components using Nd-YAG laser system are discussed in this paper.

1. Fabrication of mineral insulated (MI) coil termination in Eddy Current based Position Sensor (ECPS) for use in Prototype Fast Breeder Reactor (PFBR).
2. Laser welding of components for the fabrication of Sodium Leak Detector (SLD) for use in PFBR.
3. Fabrication of Ir-192 source holder for Branchy therapy.

DETAILS OF LASER SYSTEM

The laser welding system currently available in Metallurgy and Materials Group of IGCAR is Nd-YAG pulsed solid state laser system with major specifications as given in Table 1.

LASER WELDING OF MI COIL TERMINATION ARRANGEMENT OF ECPS FOR USE IN PFBR

In the 500 MWe PFBR which is under construction in Kalpakkam, there are three diverse safety rods (DSR) in the core, which during normal operation of the reactor are held outside the active core region by the respective Diverse Safety Rod Drive Mechanism (DSRDM). Whenever there is a SCRAM (reactor shutdown) signal, the electromagnet holding the rod gets de-energized and the DSR falls under gravity. At the end of free fall, the DSR is decelerated by a sodium dashpot and is brought to rest. The free fall time of DSR during SCRAM under normal operating condition is to be less than 1 second, including the response time of the electromagnet. ECPS is planned to be used for detecting the free fall of the DSR. Total length of the ECPS coil is around 100 meter and at both the ends, coil termination has to be carried out. This coil termination arrangement was carried out using laser welding. Suitable design of termination was arrived at after conducting many trials. Fig. 1 shows the general coil termination arrangement of ECPS and the welds to be carried out.

Table 1 : Majoı specifications of laser welding system available

Average power on the job	150 W
Maximum pulse energy	80 J
Range of current adjustment	100 to 300 A in steps of 1 A
Pulse width	0.5 to 20 ms in steps of 0.5 ms
Frequency	1 to 100 Hz
Beam delivery	Direct beam and two 400 μm fiber optic delivery
Focal spot range	200 to 1000 μm
Gas protection for the job	Argon
Work station	3 axes CNC controller with positioning accuracy of ± 2 μm
Maximum job weight	100 kg

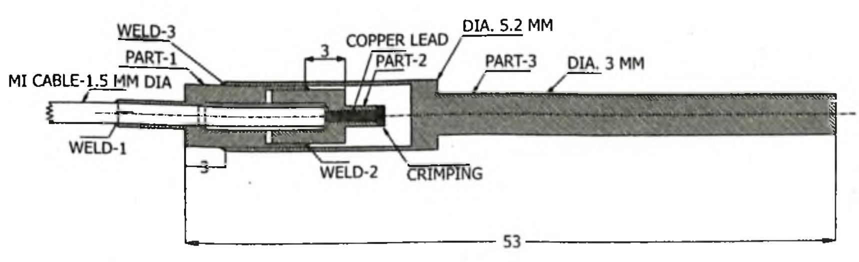

Fig. 1 : Sketch showing the general coil termination arrangement of ECPS

e three welds to be carried out in ination region. The first weld is the MI cable sheath and 2 mm ameter portion of part no.1. The weld is between 4.6 mm inner r portion of part no.1 and part he third weld is between part d part no.1.

the start of weld-1, the ons of the MI cable were ed and found that the thickness tainless steel sheath used in the le was 0.13 mm. From the MI stainless steel sheath was d carefully to a length of 5 mm to the copper lead and part no. 1 serted into the MI cable and to a suitable length. Then, part is inserted into part no. 1 and the lead was passed through the portion (dimensions: 1.5 mm ameter and 3 mm length) of part opper lead and the sleeve of part were crimped using a specially ed tool. Subsequently, weld no.1 rried out between stainless steel of MI cable and the part no. 1 d by weld no. 2 between part no. , and weld no. 3 between part no.

ser parameters used for carrying welding operations are shown in 2.

entire welding operation the MI was heated to 120°C to remove oisture that would have entered the cable, using a specially made g setup.

mpleted welds were subjected to and radiographic inspection. The cation welds which were carried rior to the actual welds, were cted to visual, radiographic tion and helium leak testing to a f less than 10^{-8} std cc/sec. Fig. 2

Table 2 : Laser parameters used for carrying out the welding operations of MI coil termination arrangement of ECPS

	Weld no. 1	Weld no. 2	Weld no.3
Average current (A)	110	150	160
Pulse width (ms)	12	10	10
Frequency (Hz)	9	11	11
Focus lens used (mm)	100	100	100
Gas shield	Argon	Argon	Argon
Indexing (through Siemens CNC drive)	10°	5°	5°

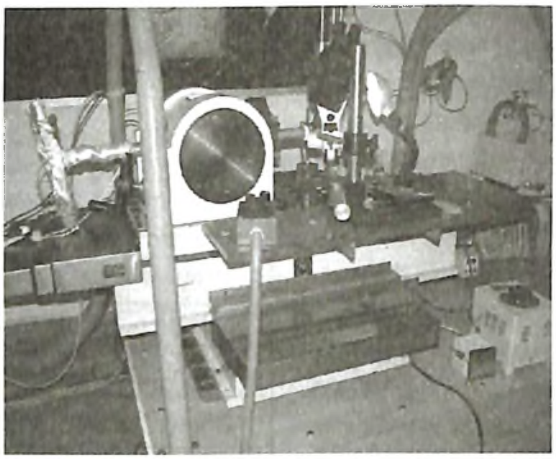

Fig. 2 : Photograph of laser welding set up for the ECPS coil termination arrangement

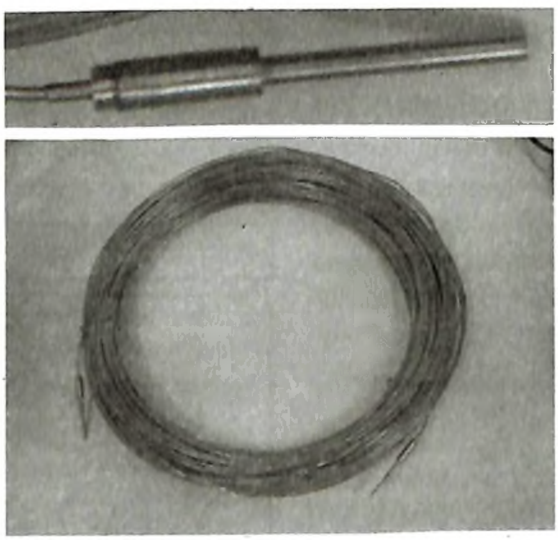

Fig. 3 : Photographs of completed ECPS coil termination arrangement

shows the photograph of the laser welding set up and Fig. 3 shows the photographs of the completed job.

LASER WELDING OF COMPONENTS FOR THE FABRICATION OF SODIUM LEAK DETECTOR (SLD) FOR USE IN PFBR

SLD is housed inside the electromagnet assembly of DSRDM of PFBR to indicate if there is any leakage of sodium into the electromagnet. The fabrication of SLD required precision laser welding of few of its components. Laser-welding was carried out after standardization of procedures involved. SLD consisted of four components: pocket, sensor flange, support tube and bobbin. Figure 4 shows the sketch of sodium leak detector. The first weld is between the support tube and the sensor flange. Part of the support tube was inserted into the sensor flange and welded. This is a fillet weld by laser welding process. After winding 0.5 mm diameter MI cable on bobbin, the free leads of winding were inserted into support tube and the leads were taken out through the holes on the sensor flange of the above assembly. After taking out the free leads, bobbin was inserted into support tube of the above assembly and tack welded using laser. This was the second weld.

Following operations were carried out for each of these two welded joints: standardization of laser welding parameters, metallographic sample preparation and examination of cut sections of welds as per prescribed procedure, and actual welding of components as per Welding Procedure Specification (WPS) prepared, followed by inspection. During weld qualification three consecutive welds were examined for depth of penetration by metallographic examinations in addition to dye penetrant test and visual examination.

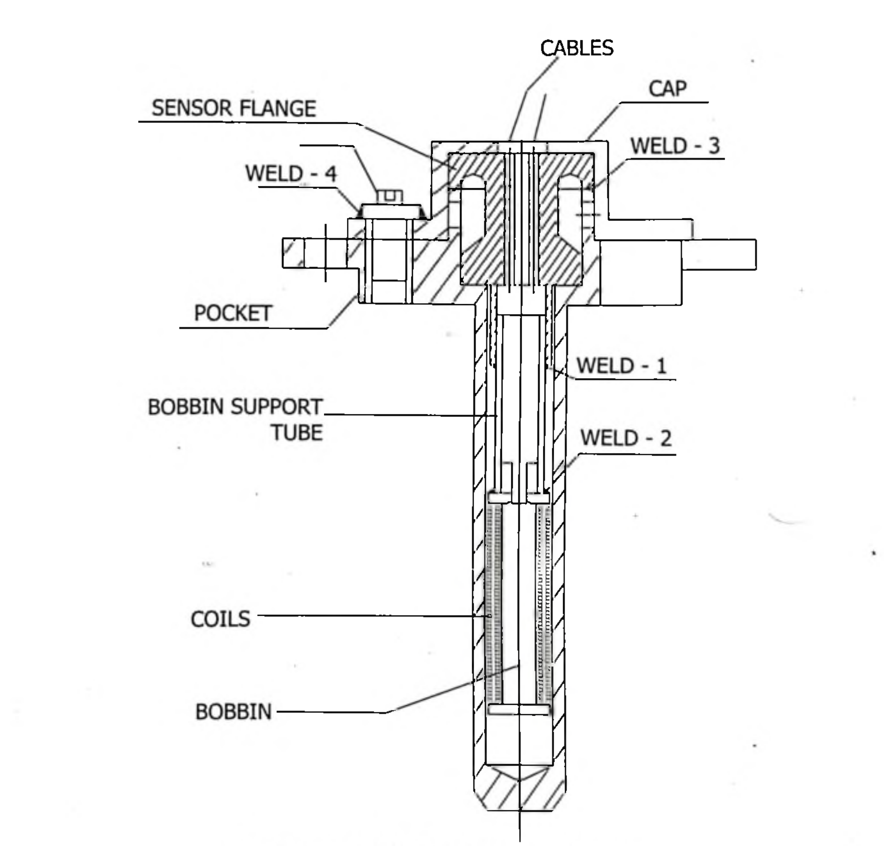

Fig. 4 : Sketch of sodium leak detector

One pre and one post weld samples were destructively tested before and after the actual welding.

Finally, sensor assembly was inserted into the pocket and was tack welded using laser at two places. Then a cap was kept in position, fastened to the pocket using the screws. The screws were then welded at two places by laser welding. These are the third and fourth welds respectively. A total of four such sets of SLDs were fabricated.

Welding parameters used to carry out the laser welding are given in Table 3 and Fig. 5 shows the photograph of the completed sodium leak detector.

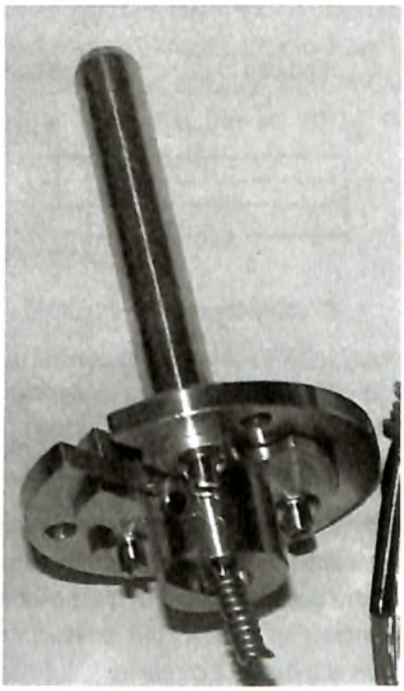
Fig. 5 Photograph of completed sodium leak detector

FABRICATION OF Ir-192 SOURCE HOLDER FOR BRANCHY THERAPY

Board of Radiation and Isotope Technology (BRIT), Mumbai is planning

There are three welds to be carried out in the termination region. The first weld is between the MI cable sheath and 2 mm outer diameter portion of part no.1. The second weld is between 4.6 mm inner diameter portion of part no.1 and part no.2. The third weld is between part no.3 and part no.1.

Before the start of weld-1, the dimensions of the MI cable were measured and found that the thickness of the stainless steel sheath used in the MI cable was 0.13 mm. From the MI cable, stainless steel sheath was removed carefully to a length of 5 mm to expose the copper lead and part no. 1 was inserted into the MI cable and pushed to a suitable length. Then, part no.2 was inserted into part no. 1 and the copper lead was passed through the sleeve portion (dimensions: 1.5 mm inner diameter and 3 mm length) of part no. 2. Copper lead and the sleeve of part no. 2 were crimped using a specially developed tool. Subsequently, weld no.1 was carried out between stainless steel sheath of MI cable and the part no. 1 followed by weld no. 2 between part no. 1 and 2, and weld no. 3 between part no. 1 and 3.

The laser parameters used for carrying out the welding operations are shown in Table 2.

During entire welding operation the MI cable was heated to 120°C to remove the moisture that would have entered inside the cable, using a specially made heating setup.

The completed welds were subjected to visual and radiographic inspection. The qualification welds which were carried out prior to the actual welds, were subjected to visual, radiographic inspection and helium leak testing to a level of less than 10^{-8} std cc/sec. Fig. 2

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Gas shield	Argon	Argon	Argon
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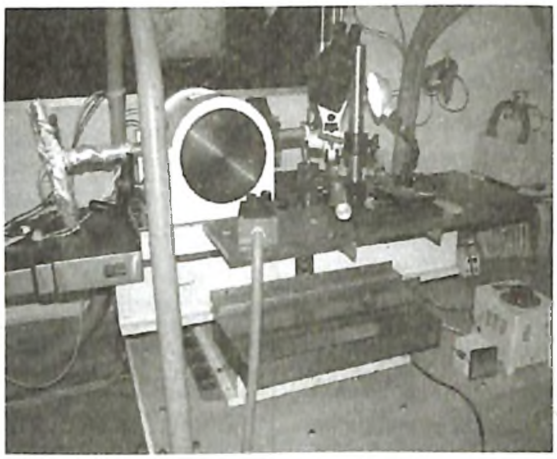

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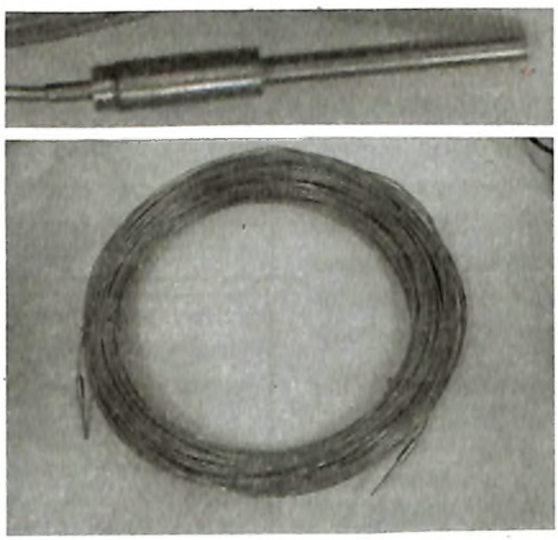

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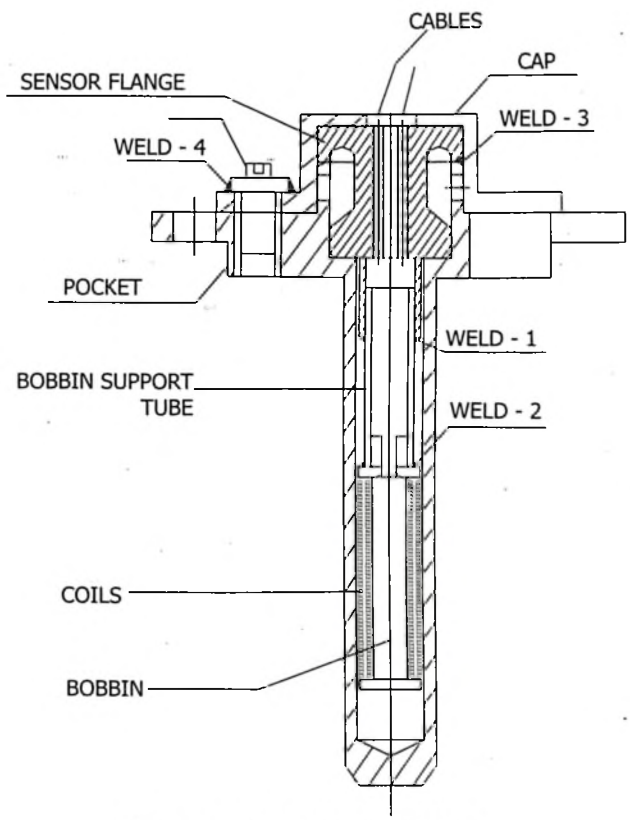

Fig. 4 : Sketch of sodium leak detector

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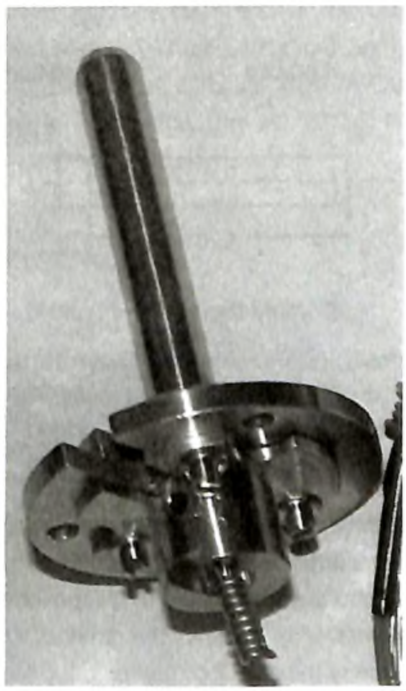

Fig. 5 Photograph of completed sodium leak detector

FABRICATION OF Ir-192 SOURCE HOLDER FOR BRANCHY THERAPY

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Table 3 : Welding parameters used to carry out the laser welding of components of SLD					
Shielding gas: Argon				Focal length: 100mm	
Weld Location	Current (A)	Pulse width (ms)	Frequency (Hz)	Number of burst(s)	Index
Fillet welding between bobbin support tube and sensor flange (Weld-1)	180	10	11.5	2	5°
Fillet welding between bobbin and support tube (Weld-2)	180	10	11	2	5°
Tack welding between sensor assembly and pocket	170	9	11	1	Two tacks
Tack welding of three screws	180	10	11	1	Two tacks

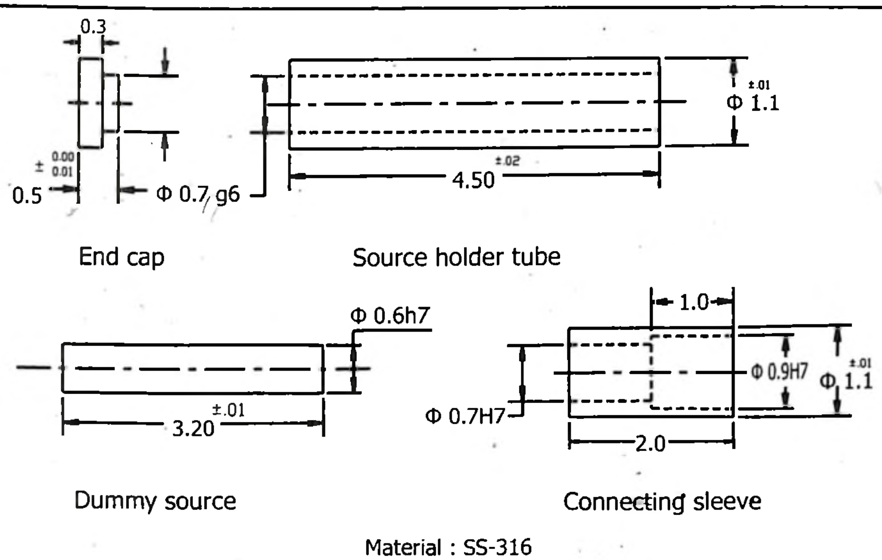

Fig.6 : Ir - 192 source container components

to develop Ir-192 source assembly indigenously for use in Branchy therapy. Branchy therapy is used to treat cancer patients. Fig. 6 shows the dimensional details of the source container.

Establishing the feasibility of fabrication and welding of the precision miniature components required for Ir-192 source holder was taken up in IGCAR. As part of this work, following precision works have been carried out:

a. Source holder tube (1.1 mm OD and 0.7 mm ID) and 0.5 mm thick end cap have been machined

b. Connecting sleeve of 2 mm length with 1.1 mm OD and 0.9 mm ID at one end and 1.1 mm OD and 0.7 mm ID at the other end has been machined

Following laser welding works have been carried out using the machined components:

a. Welding of 0.7 mm diameter wire rope to the source holder tube on one side (Weld-1) and welding of end cap to the source holder tube on the other side (Weld-2). This source holder is meant to hold a very small quantity of radio-isotope.

b. The source holder is connected by a rope of 0.7 mm diameter for a specific distance followed by another wire of 0.9 mm diameter. The connecting sleeve for the wire ropes has been laser welded with 0.7 mm wire rope on one side (Weld-3) and 0.9 mm diameter wire rope on the other side (Weld-4).

The assembly of Ir-192 source holder is shown in Fig. 7.

All welding operations were carried out in a special inert chamber designed and fabricated for this purpose. Wire ropes were cut without burr using electric discharge machining (EDM) process. Overlapping spot welds were carried out. A dummy source was kept inside the source holder.

Two sets of the above assembly have been fabricated for testing and evaluation at BRIT. The welds were reported to be of good quality.

The welding parameters used in this fabrication are given in Table 4. The photographs of welding operation and the completed Ir-192 source container are shown in Fig.8 and Fig.9 respectively.

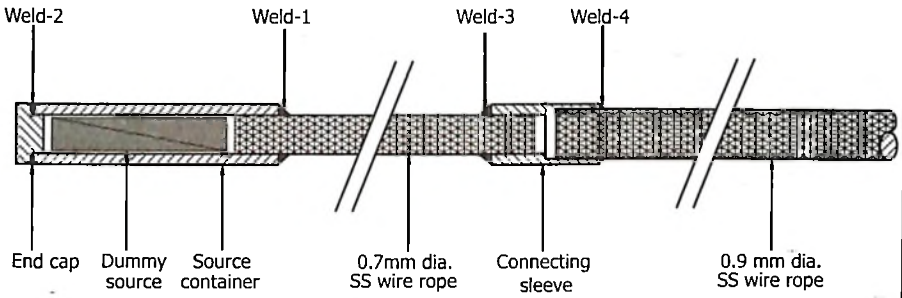

Fig. 7 Assembly of Ir -192 source holder

Table 4 : Welding parameters used to carry out the laser welding of components of Ir-192 source holder

	Weld-1	Weld-2	Weld-3	Weld-4
Average current (A)	108	105	110	108
Pulse width (ms)	10	5	9.5	10 s
Frequency (Hz)	10	6	11	10 z
Focus lens used (mm)	100	100mm	100	100
Gas shield	Argon	Argon	Argon	Argon
Indexing (through Siemens CNC drive)	20°	15°	20°	20° ive

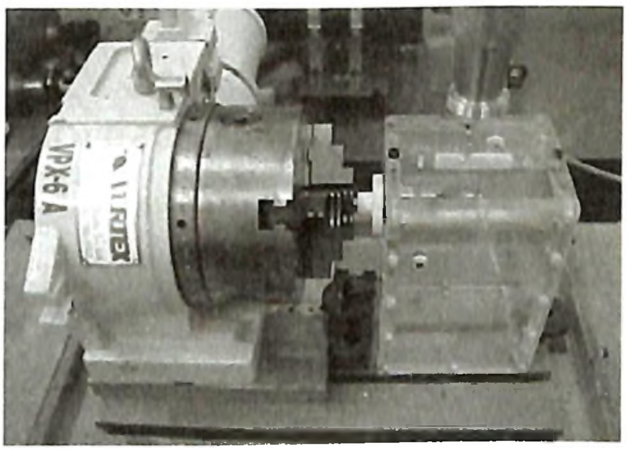

Fig. 8 Photograph of welding operation of Ir-192 source container

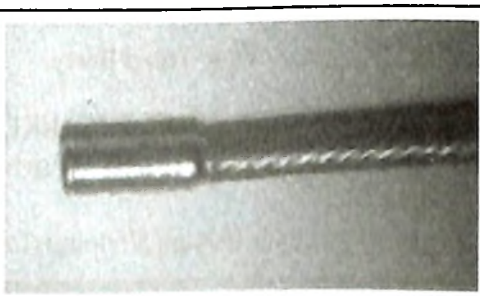

Fig. 9 Photograph of completed Ir-192 source container

CONCLUSION

Laser welding of precision components for Eddy Current based Position Sensor and Sodium Leak Detector in Diverse Safety Rod Drive Mechanism of Prototype Fast Breeder Reactor has been successfully completed. Feasibility of indigenous fabrication of Ir-192 source container for Branchy therapy has been established. Each activity required efforts to standardize the welding parameters and in some cases specially designed chamber or heating set up to achieve good quality welds.

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REFERENCES

1. http://physicsnobelprize.net/
2. Christopher Dawes (1992): Laser Welding: A Practical Guide, Abington Publishing - from Google Books Result - http://books.google.co.in/