Lasers and Their Potential in Production at GE

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ABSTRACT

Laser technology has been used in manufacturing in industry since the late 1960s. Industry and GE businesses have leverage laser welding for productivity gains, cost savings, and quality. The presentation will high light several laser-based welding applications, old and new. Applications will include the welding of refractory materials (e.g. Mo and Nb) for lighting products; 40 foot long fuel rods are welded with 2 kW fiber lasers for the nuclear business; head-liner welding for the diesel engine for locomotives (14 kW fiber laser replaced CO_2 laser); and X-ray components are welded in a two-station 11kW fiber laser (EB welding replaced by laser). The three fiber laser applications were all transitioned into GE businesses during 2011 and it demonstrates the emergence of fiber laser welding being used in GE for manufacturing, processing.

1. INTRODUCTION

GE has had a very long history regarding laser technology. The diode laser was invented by Robert Hall at GE Global Research and he received the patent in 1962. Robert Hall is in the National Inventors Hall of Fame because of his diode laser invention. It should be mentioned that diode lasers are the heart of many solid lasers today that are used in laser material processing. They are used as a direct laser source for material processing or they are used as a pump source for solid state lasers as well as for fiber lasers. In addition to addressing the concept of fiber laser technology, the initial entitlement of thick section welding with fiber lasers was demonstrated with stainless steel. This paper also provides examples how GE is using the technology in three of their businesses.

2. DIODE LASER INVENTION

When Robert Hall was conducting his experiments regarding the diode laser, it was never referred to as a diode laser. It was always referred to as a semiconductor injection laser. The big difference between the technology today and the technology in the very early 1960s was that the device being tested then required to be performed at cryogenic temperatures, a far cry from today's technology. Hall was indeed a true pioneer in the development of laser technology. He was interview by GE Global Research in 2010 which marked the 50^{th} anniversary for the invention of the laser. His diode laser invention was two years later in 1962. The interview can be seen on the following link: http://www.youtube.com/watch?v=ENOon8854uU. Figure 1 depicts a photo of Robert N. Hall and a schematic of the semiconductor injection laser.

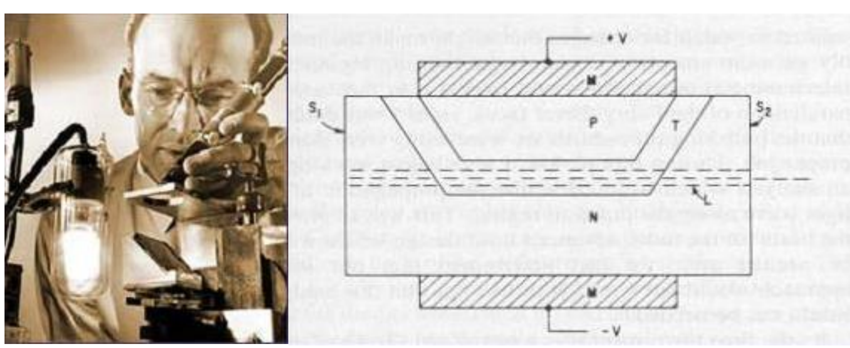

Figure 1. Depicted in a photo of Robert N. Hall and a schematic of the semiconductor injection laser

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3. FIBER LASER TECHNOLOGY

3.1Basics of fiber lasers

Fiber lasers that are used in laser material processing typically operate at wavelength of 1070 nm. The lasing dopent is ytterbium (Yb). The fiber core is doped with Yb. The lasing dopent is pumped with diode lasers that are spliced into the fiber. Fiber grating are used to establish the resonator such that mirrors are not required. Fiber lasers have been built with powers over 30kW with wall-plug efficencies greater than 25%. This opperating efficency is greater than that of Nd:YAG or CO_2 lasers that are typically used for material processing. Since there are minimum consumerables in operating such lasers, the maintainence is also a minimum. This helps to maximize the fiber laser up time as compared to previously used material processing lasers. Figure 2 highlights differences of the fiber laser than the more traditional material processing lasers.

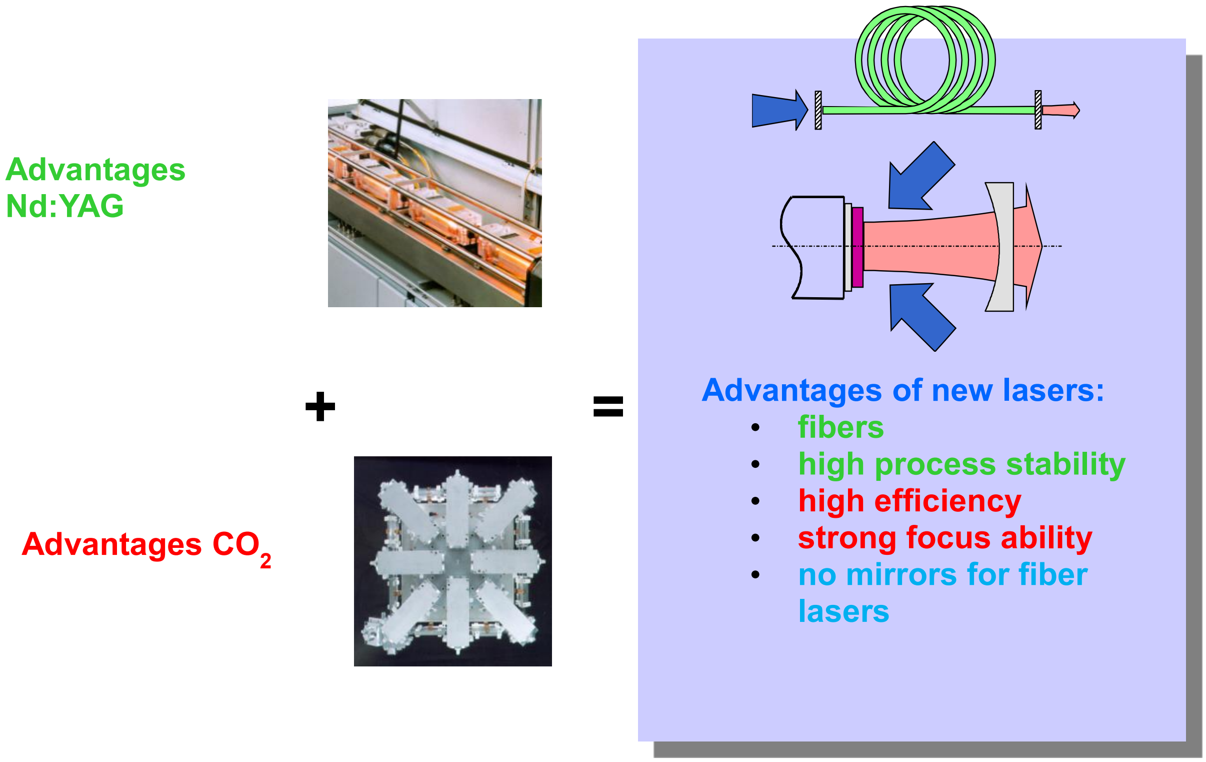

Figure 2. The fiber laser incorporates all the good characteristics of both the Nd:YAG and the CO_2 lasers.

3.2 Process Map

The operational regimes for various laser processing techniques are a function of the laser interaction time and the power density of the delivered laser beam. Laser interaction times range for very short pulses to a continuous wave (CW) mode [1]. Power densities include peak powers from a laser that's being operated in a pulse mode to average and CW. It can be seen from Figure 3 below that laser welding falls within an approximate power density range from 10^5 to 10^7 W/cm^2 and a laser interaction time from CW to a pulse width (length) that is as short as 10^{-4} seconds (0.1ms). The power density for a given laser process is dependent on the laser output power and the focus spot size which is directly related to the beam quality of the laser. When the beam quality of a laser is low, smaller focused spot sizes can be produced.

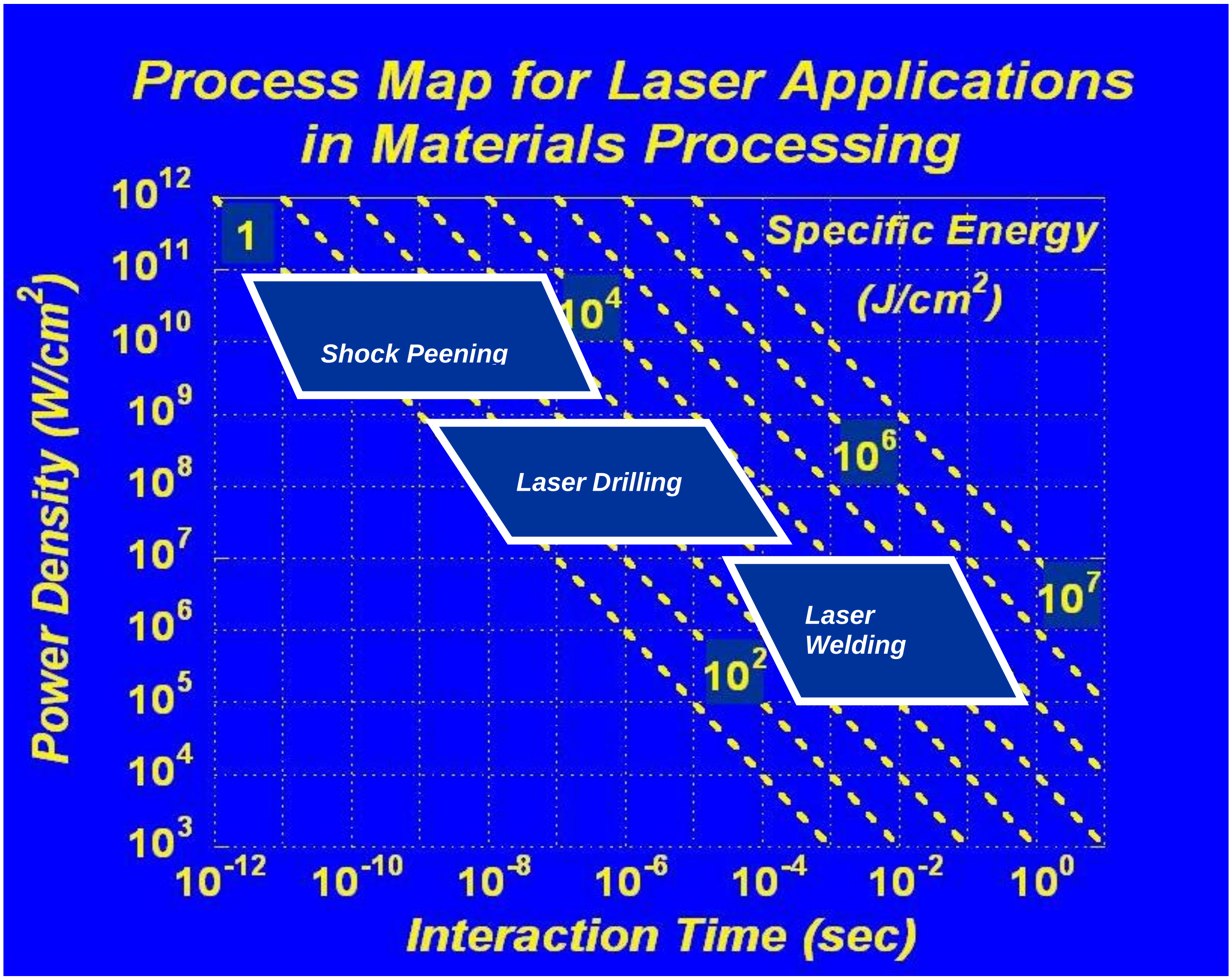

Figure 3. The operational regimes for various laser material processing techniques are shown. The regime shown for laser welding is also the regime for laser cladding

3.3 Initial Thick Section Welding with Fiber Lasers

To establish the entitlement of thick section welding with high power fiber lasers, test trials were performed with a typical stainless steel alloys. Bead on plate and butt weld trials were performed. Welding was conducted at power levels ranging between 10-20kW. The focus lens had a focal length of 310 mm. On the average, focus was ~6 mm into the surface of the 304L stainless steel substrate. The range of the welding speed was between 1-2 m/min. Argon was used as the welding cover gas and most welds were performed in the 1G position with a few in the 2G position. Figure 4 shows the cross section of butt welds for thickness between 0.75 and 1.0 inches. By welding for from opposite sides of a butt joint, successful welds achieved of thickness of 1.5 and 2.0 inches.

Figure 4a. 1.5 inch double sided butt weld (20kW, 2.0 m/min).

Figure 4b. 2.0 inch double sided butt weld (20kW, 0.6 m/min).

Figure 5 illustrates how weld penetration varies as a function of welding speed for different power levels of laser energy. These welding results were achieved with a 20kW IPG fiber laser. The welding results were achieved on 304 stainless steel. As the welding speed increases for a fixed power level, weld penetration decreases.

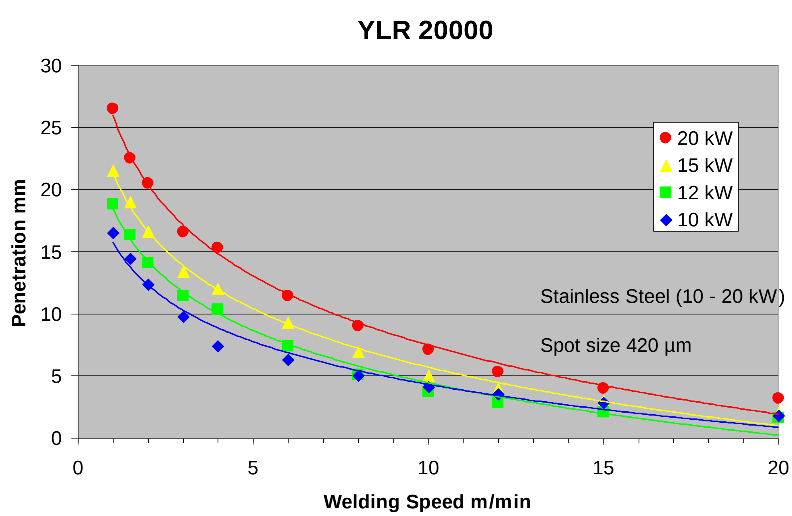

Figure 5. The graph depicts how the weld penetration decreases monotonically with increasing laser welding speed.

4. THE GE BUSINESS INSTALLATIONS

4.1 GE Nuclear Fuels

GE has used laser technology to weld fuel rod assemblies for over 25 years where CO_2 lasers were initially used. There were engineers at the Research Center that developed a weld seam tracking system because there wasn't anything that was available at that time with the desired resolution. The time frame when CO_2 lasers were being used started in 1986. This was the case because there weren't Nd:YAG lasers at that time that had sufficient power when operated in a CW mode. The switch over to the 1.06μ wavelength lasers took place in the mid-1990s. These lasers were flash-lamp pumped. In the early 2000s, there another switch to diode pumped Nd:YAG lasers. They were more efficient with reduced maintenance because changing flash lamps were not need. It is quite expensive to replace the pumping diodes in a diode pumped laser, perhaps $50-70K. It was decided in 2010-2011 to go with fiber laser technology instead of replacing the pump diodes in the old Nd:YAG laser. The fiber laser was more efficient than the diode pumped laser and there was no free-space optics in the resonator head to care for. The fiber laser was very attractive with having a 25% operating efficiency and with no or very little maintenance required.

The component that requires laser welding is the tubes of the control rod blade assembly. These tubes are ~12 feet long and are made of 304L SS. There are two opposing laser autogenously welds that are the full length of the tubes. There are two 2kW fiber lasers that are used for this task. Figure 7 shows the end of the welded control blade assembly.

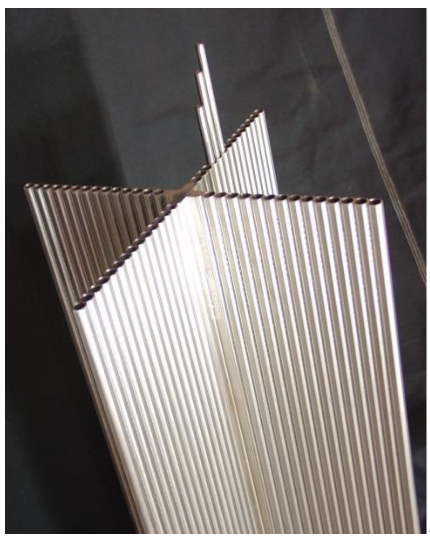

Figure 7. The end of a complete welded control blade is shown for the 14-tube D-Lattice Design.

The laser power to affect these welds is ~750W with a focus spot size of 375μ. The laser beam is focused at the surface. Helium is used as a shielding gas. Welding speed may range between 4-5 m/min. The effective weld depth is ~1.0 mm for the Marathon and Ultra Designs. These designs and related weld cross sections are depicted in Figure 8 below.

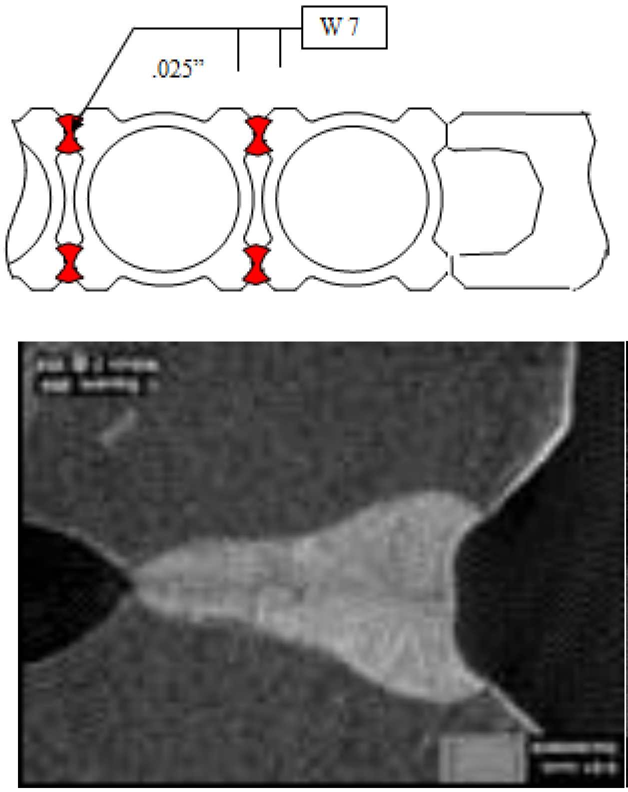

Figure 8a. Marathon Design and Weld Cross Section.

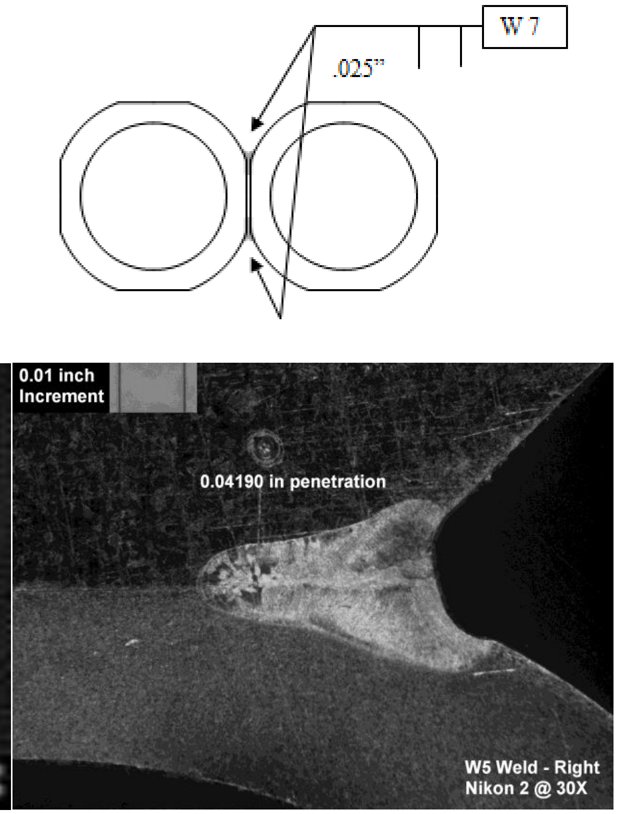

Figure 8b. Ultra Design and Weld Cross Section.

4.2 GE Transportation

The cylinder head-liner for one of the business's diesel engine products was once electron beam welded and then the process was switched over to laser welding. A high power CO_2 laser had been used for over three decades. The welding process required between 12-13kW of CO_2 laser power. To assure a robust welding process, the laser was on continuously to assure that the laser beam quality remained stable. If the beam quality was unstable, the laser beam focus could vary, leading to weld penetration variations. The operating efficiency of the laser was 7-8% which leads to a large consumption of electricity with the system on continuously. It was estimated that an annual savings between $200-250K could be realized if the CO_2 laser was replaced with a fiber laser due to a reduction in electricity usage alone. This reduction in electricity usage was due to the higher efficiency of the fiber laser and that the fiber laser only needed to on when the welding process is taking place. There was other reduced maintenance costs that were identified such as the reduction in water usage.

The weld to that is required is for a butt joint with a 0.55 inch wall thickness. The bore diameter is approximately 11 inches. The head is a cast steel (Mg, Mo) and the liner is ASTM A106 steel. A keyhole weld was performed in a 1G position with the CO_2 laser and was change to a 2G position with the new fiber laser workstation. A 14kW IPG fiber laser was selected. It is operated at 13kW to affect the desired weld. The head-liner assembly is first tact welded in four locations equally spaced around the circumference of the assembly. The continuous weld is then performed at a speed of ~1.0 m/min. A welded cylinder head liner is shown in Figure 8 and a weld cross section is seen Figure 9.

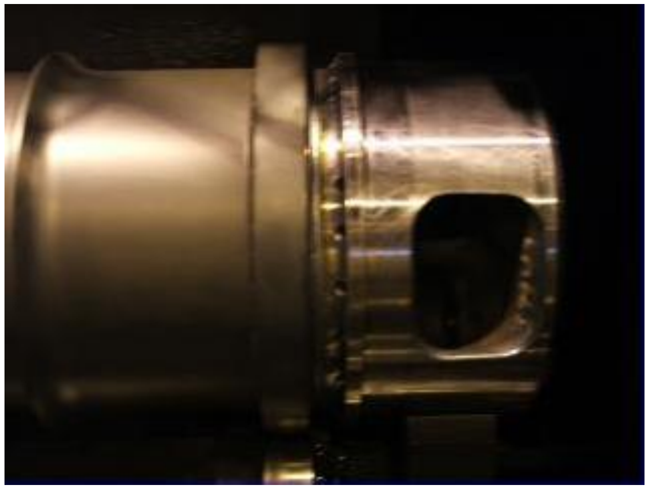

Figure 8. A completed welded diesel cylinder head-liner is shown.

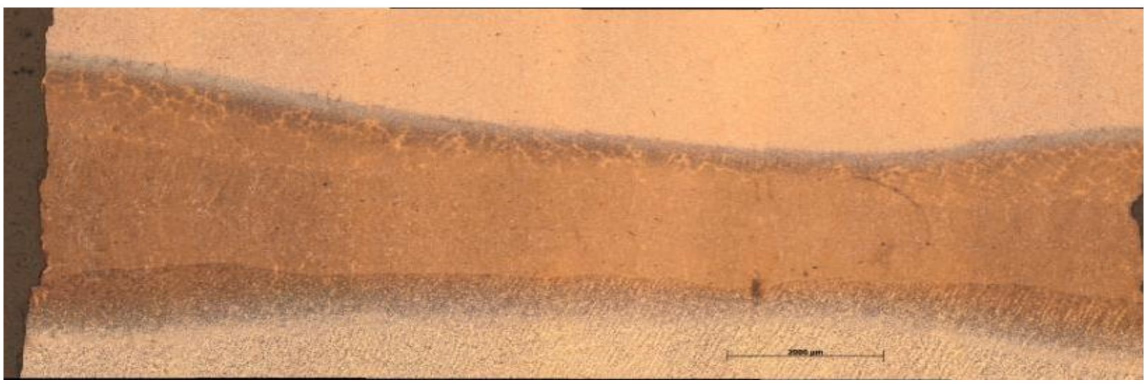

Figure 9. A cross section of the keyhole butt weld is shown with evidence of no major defects. The ASTM A106 steel is in the top of the picture and the cast steel (Mg, Mo) is in the bottom of the photo. This weld was performed at 13kW and 1.5 m/min.

4.3 GE Healthcare

The welding of two components for an x-ray tube has been developed with the use fiber lasers. The first component involves the welding of a flat tungsten emitter and the second component is a shaft that has been previously welded by electron beam. The tungsten emitter requires a pulse laser operation and the shaft weld requires a 10kW CW keyhole weld. An 11kW fiber lasers was configured to be shared between at tungsten emitter welding workstation and a shaft welding workstation. The flexibility of the fiber laser enables a pulse mode operation at ~1kW average power at one workstation and a CW mode operation at 10kW at the second workstation.

Figure 10 shows a schematic of a flat tungsten emitter that be joined initially to three tungsten posts and then to three molly post. The weld involves the use of platinum material to affect the joining process of the refractory materials. Many such welds were made and successfully tested hours at high temperatures. One important attribute of the flat emitter was its flatness. The welding process did not compromise the emitter’s flatness. The tungsten emitter is only 0.2 mm thick.

The rotor shaft weld is shown in Figure 11. In this case, a 10 mm deep weld required. The welding direction is parallel to axis of the rotor shaft assembly and is in a 1G position. The materials that are being welded are 909 Incoloy and 1018 Steel. The Incoloy cylindrical component is pressed fitted into the counter bore of the steel component thus forming an ideal interface for a keyhole weld. The weld does not require a vacuum chamber. It only requires a cover has such as nitrogen, argon or helium.

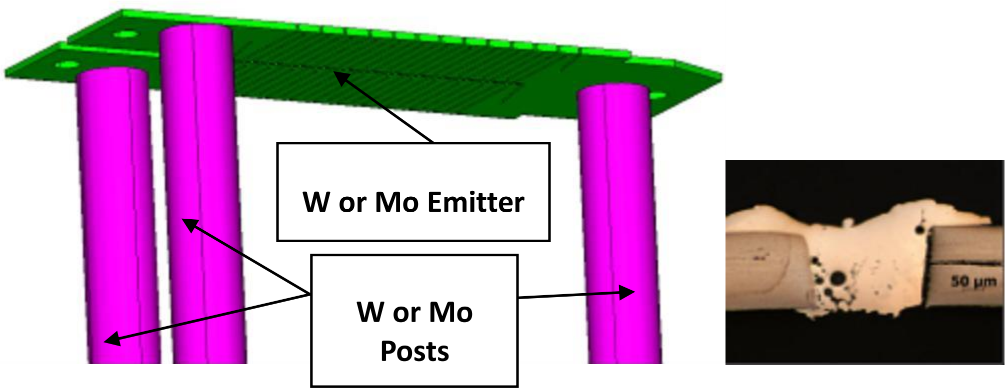

Figure 10. Shown is the schematic of the tungsten emitter mounted on the posts. It is fixture in place for the welding process. The cross section shows the flow of the platinum.

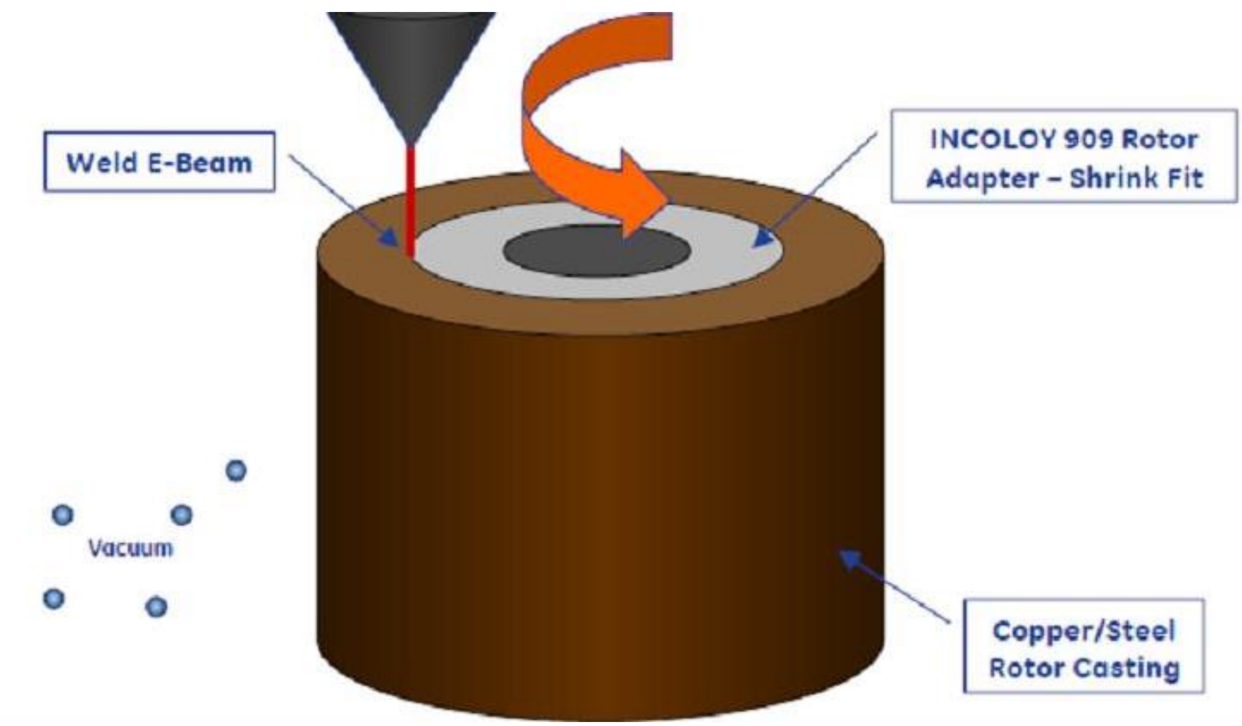

Figure 11. The schematic depicts the weld process of the rotor with an E-Beam process. A high brightness fiber laser is being used in place of an E-beam system to affect the required 10 mm weld depth.

5. CONCLUSITION

This paper has highlighted the importance of diode lasers. It has also highlighted some early thick section welding results with fiber laser technology. These results have led to the business deciding to use the technology from manufacturing welding processes that have resulted in more robust processes. The technology choice has resulted in processes with higher first time yield, high weld quality, lower weld operating, and less equipment maintenance.

6. REFERENCE

[1] Laser Materials Processing, W.M. Steen and J. Mazumder, Springer-Verlag, 4th Edition, 2010.