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Production Applications for High Power Diode Laser Systems – Case Study

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ABSTRACT

To date there has been many applications described for direct diode laser systems but few have been implemented in extreme production environments. We discuss several of these applications in which the direct diode laser have been implemented and proven cost-effective in production environments. These applications are laser hardening, laser cladding, laser paint stripping and laser welding and brazing. A comparison of the advantages and disadvantages of the direct diode laser versus traditional industrial lasers such as CO2 and Nd:YAG and non-laser technologies such a TIG, MIG, and plasma for each of these production application is made.

Keywords: Diode Laser, Direct Diode Laser, Hardening, Welding, and Paint Stripping

1. OVERVIEW

This paper will summarize the results of two successful High Power Direct Diode Laser (HPDDL) system production installations after over one year in service. The cost savings and performance improvements are dramatic in each case as well as the high reliability and low maintenance experienced with the diode laser system. This paper will also summarize surface modification treatments currently being explored by Nuvonyx. These treatments include; Case hardening, cladding with powder feeder and cladding with thermal spray technology, and paint stripping,.

2. HPDDL HEAT TREATMENT PRODUCTION INSTALLATION

2.1 Overview

A 4 kW HPDDL system was installed into an industrrial production line to provide the heat treating required for a large steel part. This installation was a complete success because the quality of the heat treating was improved and the installation costs were recovered in less than a year because of the low installation and operating costs.

2.2 Decision

The production processes had been performed by a lamp pumped Nd:YAG laser for the last two years. However, the Nd:YAG laser was not well suited to this application because of the high maintenance of the system and the inability of the system to maintain power level during long processing cycles.

These problems caused significant delays in production which increased the costs of producing the parts. It was clear that a better method of heat treating these parts was needed. Several technologies have been tried to date including; induction heating, CO2 laser heat treating and Nd:YAG laser heat treating with less than adequate results. However, the initial test results using the new HPDDL technology produced very promising results. Consequently, a HPPDL system was set up for trial testing and after several months of working with the system it became clear that the HPDDL has four primary advantages over other laser systems.

The first advantage is the low installation cost for the HPPDL. The HPDDL system has no special power requirements, no special cooling requirements and no special environmental requirements other than the laser safety enclosure. In addition, the HPDDL system manufactured by Nuvonyx is controlled by a microprocessor that can easily be programmed to mimic the input control of a Nd:YAG laser. Finally, the HPDDL is sufficiently small, that the entire unit was mounted on the robot in place of the current fiber coupled beam delivery system. The set-up, installation and checkout of the HPDDL system is straight forward compared to other more complex laser systems and was accomplished in less than one day

The second advantage is the low operating cost of the HPDDL due to the high electrical conversion efficiency of the system. The 4 kWatt HPDDL system, complete with the water to air chiller, consumes less than 16 kW of electrical power during operation. In contrast, an equivalent lamp pumped Nd:YAG laser will consume between 350 kWatts and

400 kWatts for the same output power. This low input power requirement is one of the primary reasons for the low installation costs of the system.

The third advantage for the HPDDL is its very stable output power during operation regardless of the heat feedback to the system. The Nd:YAG laser on the other hand tended to heat up during the long heat treating cycles and slowly lost power during the process. This was causing some quality problems at the end of the process cycle where the hardness of the material would decrease due to the lower power level of the Nd:YAG laser.

The forth advantage for the HPDDL is the high reliability of the all solid state system. Prior to this installation, the HPDDL was shown to be reliable in several applications development centers; this would be the first production installation, where the ruggedness of the system would be truly tested. This was a major issue during the evaluation period because the reliability of the system was still unproven. However, the laser proved itself to be highly reliable by posting a >99% up time record during the first year of operation.

2.3 Integration

Nuvonyx Inc. worked closely with the customer and the software company to completely retrofit an existing laser workstation. The laser workstation consisted of a 6 axis robot for handling the laser, a large horizontal indexer for rotating the parts, a laser safety enclosure with automatic door opener and an external remote control panel. The upgrades included changing the mechanical mounts on the end of the robot, changing the type of safety glass on the enclosure and developing software that would enable the HPPDL to mimic the control commands of the Nd:YAG laser. Nuvonyx worked closely with the customer and a third party software provider to develop this proprietary software package.

Nuvonyx Inc. worked closely with the customer to develop the processing parameters required to achieve the necessary hardness on the parts. The hardness specification was easily achieved using a self-quenching heat treating process. The case depth on the parts is approximately 1 mm with Rockwell hardness in the range of 55-65 depending on the base material.

A significant improvement in the process tolerance was achieved by using an optional output optic that decreased the focussing of the beam in the fast axis and allowed the depth of focus to be expanded by over 1 cm. This allowed the part to be placed on the turntable without it having to be accurately registered and enabled the robot to be programmed without having to first access a reference point and offset its program. In addition, the optional optic also maximized the case depth without increasing the track-to-track back temper.

2.4 Results

The laser system was installed in June 2002 and has been operating up to two shifts a day depending on the production backlog. The maintenance cost was reduced by a factor of 300 from the previous year and the up time for the laser was better than 99% for the year. In addition, the process time for one part was reduced from 90 minutes to 30 minutes and the back-temper for each part was less than 5% which is substantially better than the parts processed with the Nd:YAG laser.

The improvements in the process speed are a result of several factors which include the beam shape, the absorption by the part, the stability of the laser and the reliability of the laser. The ISL-4000L standard beam is 12 mm x 0.5 mm, but with the addition of the optional optic, the beam is 12 mm x 6 mm. The optional optic reduces the chances of surface melting during the process and increases the case depth because the material is held at a higher temperature for a longer time period.

The absorption of the HPDDL beam by the part is substantially higher than for the longer wavelengths of either the CO_2 laser or the Nd:YAG laser. In addition, the HPPDL is highly polarized which further enhances its absorption. At elevated temperatures, the absorption rate of the highly polarized beam can exceed 90%. The net result is that the process can proceed at a faster rate when using a highly polarized beam compared to an unpolarized beam at the same power level.

The high stability of the HPDDL enables the parts to be processed open loop. The HPDDL output power is measured and tracked on a weekly basis. Over the last year the power level has been very stable. In addition, even during the processing of the part, the output power of the HPDDL is very stable indicating minimal heating in the HPDDL system. The HPDDL on the other hand, with its exceptional stability greatly improved the productivity of the laser heat treating cell.

In summary, the installation of a 4 kW HPDDL system into an industrial production line to perform a critical heat treating process has been a tremendous success. Part yield has been increased substantially, labor hours per part to process have been decreased substantially, maintenance has dropped to a very low level and the system has paid for itself in less than one year.

3 HPDDL Welding Production Installation

3.1 Overview

A 4 kW HPDDL system was installed into a production line to weld the sub-cell of launch canisters for the US Navy's MK 25 Vertical Launching System at United Defense [1]. The company replaced a conventional Metal Inert Gas [MIG] arc welder with a 4 kW HPDDL system. This enabled them to simultaneously reduce the manufacturing labor content for the part while increasing the quality of the welds.

3.2 Decision

The company had been manufacturing launch canisters using a conventional MIG welding process. However, this new sub-cell is made of a thin corrugated skin that is reinforced with multiple braces. The heat input from the MIG process caused so much distortion that it was difficult to manufacture the sub-cell to the requisite tolerance. The company needed to develop a process that would allow them to perform the eight long welds on the container without distortion.

Each sub-cell has eight 4.8 meters long welds between the 2mm thick skin and the 5 mm thick corner braces. The distortion in the sub-cell resulted in extensive post weld activities in machining and assembly to deal with that distortion. Based on these results United Defense had to find a way to reduce the heat input to the sub-cell. Two laser techniques were studied, a Nd:YAG laser which performs a keyhole weld with a micro-wire feeder and a HPDDL which performs a conduction weld with a wire feeder.

After a series of tests with both lasers, the HPDDL proved to be more tolerant to the poor part fit up, enabled a high quality weld with minimal distortion and produced no spatter on the inside of the part. This is a result of the beam shape of the HPDDL which is better suited to parts with poor fit up and is easy to use with a wire feeder.

The final step of the evaluation was to rate the performance of the two laser technologies. At the time the reliability of the HPDDL was unproven in the production environment, so the company rated the HPDDL the same as the Nd:YAG laser. The decision to use the HPDDL was the result of the higher rating marks received on the quality of the welds and the ability to produced a weld without spatter on the inside of the part rather than any technology advantages.

3.3 Integration

The ISL-4000L laser was installed on the existing 10 kg Panasonic robot. The MIG torch was removed and the laser was installed in its place. A Panasonic wire feeder was also installed with the laser to provide the filler material. There was no special power requirement for the laser other than the 480-30 Amp, 3-phase service that was already available at the installation site. Therefore, the only installation costs for implementing the HPDDL for welding was the HPDDL itself, some simple hardware for mounting the laser to the robot, and a laser safety enclosure.

Some of the challenges with the weld included how to position the laser beam, how to introduce the wire into the weld puddle and finally how to manipulate both the laser and wire feeder in such a way as to maintain a good, full penetration weld along a corrugated metal part. Nuvonyx developed a process capable of meeting all of these challenges, but it requires the robot system to know the exact location of the two parts to be welded and their start and stop locations.

A Sense-I Gauge sensor from Servo-Robot Inc., of St. Bruno, Quebec, Canada was integrated onto the robot to allow the system to track the seam between the thin metal sheet and the side rails. This system uses a low-power laser to measure part placement to calculate welding offsets. Because it is based on a non-contact optical technology it provides a very fast response and allows the robot to move to reference points and rapidly calculate the welding offsets. These offsets are then used as a reference for the robot to position the laser beam correctly.

The last challenge in the installation was how to keep the output window of the laser clean. Several techniques were tried, but the best window lifetime was achieved with a simple air-knife mounted directly on the laser itself. The weld spatter was also minimized by using Argon – CO2 cover gas on the weld puddle and optimizing the wire feed into the puddle.

3.4 Results

The company has successfully welded 240 sub-cells with a total of 38.5 meters of welds per sub-cell using the HPDDL system this year. The laser system was capable of welding the sub-cell at the same rate as the MIG process; however the labor associated with manufacturing this sub-cell dropped by 30%. This decrease in the labor was a direct result of the less thermal distortion causing less post weld processing. In addition, the HPDDL system used 1/5 of the wire to do the same job as the MIG process. The MIG process required up to 4.5 kg of wire to complete canister while the HPDDL process required only 0.9 kg of wire per canister.

The laser system, wire feeder, integration service, and process development service was all provided by Nuvonyx Incorporated. The laser achieved the same up-time performance as the heat treatment installation of >99%. There was however some minor maintenance associated with the laser mainly due to spatter from the weld process. In one instance the laser was operated without the window and the internal optic was contaminated by the spatter. Production however did not have to stop to replace the optic; the system was operated until the weekend when it was convenient for the system to be returned to Nuvonyx for replacement of the optic. The laser head was shipped via overnight express on Friday arrived Saturday and was returned ready for production by Tuesday. The HPDDL is the only type of industrial laser that can be returned to the factory for service and returned to production, sometimes in less than 48 hours

The cost of this installation was recovered during this production run as a result of the significant savings in the labor and materials to manufacture each sub-cell. The low operating and maintenance costs of the system also contributed to the rapid recovery of the investment in the laser system.

4 Surface Treatment Job Shop

4.1 Overview

Nuvonyx is currently providing heat treating and cladding job shop services while Lancorp Advanced Systems Incorporated, Oakdale, PA, is providing paint stripping services. The heat treating and cladding processes are relatively straight forward processes for the laser where the laser is operated CW during the process. The paint stripping operation however is entirely different; here the laser is pulsed at rates up to 10 kHz to allow the paint to be ablated from the surface without burning.

Nuvonyx Incorporated has a complete job shop facility capable of handling linear parts up to a meter in length or cylindrical parts up to 50 cm in diameter. The laser is mounted on a Panasonic VR-16 robot and has access to work tables, a rotary stage and an indexer. Material can be added to a melt puddle with a wire feeder, a powder feeder, a strip feeder, pre-sprayed by a thermal spray process or preplaced on the surface. The laser can be used open loop, or an emissivity independent pyrometer can be used to control the laser power and the surface temperature of the part. Nuvonyx Incorporated has access to a complete metallurgical lab for analysis of the material properties after processing of sample parts to provide feedback on the results of the process.

4.2 Heat Treating Services

Nuvonyx has extensive experience with using the ISL-4000L HPDDL to heat treat a variety of materials and components. Table I summarizes the types of materials, the hardness, and the case depth that has been achieved for each material using the ISL-4000L. Most heat treated processes used by Nuvonyx are based on the self quenching of the surface. For cases where the mass of the part is insufficient for a self quench operation, Nuvonyx has developed processes based on a water cooled quench process. Nuvonyx can readily heat treat any part manufactured from heat treatable materials.

Nuvonyx is currently performing heat treating services for a wide range of customers. Parts that are currently being heat treated using the ISL-4000L include; automobile engine components, diesel engine components, large engine components for trucks, tractors and ships, hand tools, tooling for oil drilling, pump impellers and saw blades. These are just a sample of the many components that Nuvonyx is capable of processing.

Nuvonyx has also developed a pyrometer feedback system for the direct control of the temperature at the surface. Nuvonyx uses a fiber optically coupled pyrometer from Williamson Corporation, Concord, MA, to provide an emissivity insensitive measurement of the surface temperature. This pyrometer was specifically developed for Nuvonyx with a response time of 1 mseconds to allow high speed control of the laser in response to changes in the surface. An example of using a pyrometer to control the surface temperature is shown in Fig.1. In this figure, the surface temperature is preset by the program and the laser, under the control of the pyrometer, rapidly slews to the correct setting. An IR camera is monitoring the heat zone to confirm that the preset temperature is achieved. The control loop is very stable using the diode laser because of the accurate and linear performance of the laser diode electronics. This technique can be applied to most components, providing a means of real time feedback on the process.

The ISL-4000L standard beam is 0.5 mm x 12 mm and has sufficient intensity to cause melting of the surface if not careful in the process. To improve the process, an optional lens is added at the output of the laser to greatly increase the depth of focus in the fast axis. This added depth of focus greatly reduces the tolerances on the positioning of the part and the dwell time on the part. Also due to the lower intensity, it enables the dwell time to be substantially increased without causing any melting of the surface. The result is a much deeper case depth while still maintaining a small back temper from track to track.

4.3 Surface Cladding

Nuvonyx has developed a range of surface cladding processes using a wire feeder, powder feeder, thermal spray or preplaced powder. Laser cladding is a viable alternative to plasma spraying and TIG or MIG processes. It is difficult to produce a clad with a TIG, MIG or plasma spray system without having less than 5% dilution, therefore, as many as 15 overlapping passes may be required to obtain an undiluted clad layer [2]. The HPDDL cladding has demonstrated flatter clads than that obtained with all other processes including CO2 and Nd:YAG lasers[3]. Most cladding materials can be applied as a powder, but the best clad performance is achieved with thermal spray materials. These clads tend to have the flattest surfaces because the material is bonded in place by the thermal spray process which prevents the material from flowing toward the center of the beam and producing a non-flat clad.

Nuvonyx has showed that materials such as carbide filled alloys can be readily deposited on both steel and stainless steel substrates. Single crystal super alloys can also be readily deposited on nickel super alloy substrates. This cladding technique is currently being developed for the repair of steam turbine blades [4]. These blades tend to erode during operation and replacing the blades represents a very expensive repair cost. If the blades can be repaired by building up the material and then machining the parts back to net shape the cost savings can be substantial.

5 Pulsed Operation of Laser Diodes

Nuvonyx has extensively tested its laser diodes for the industrial applications, using test procedures, which thermally cycle the laser diodes. Nuvonyx has showed that after 498 Million cycles the laser diodes have the same performance as if they had been operated CW. This is a unique feature of the Nuvonyx laser diodes and it enables our lasers to be rapidly pulsed or switched on and off without any concern over degrading the performance of the laser diodes.

We have performed several pulsed tests of our laser diodes, in our first test, a high power laser diode array (21 bars) was cycled on and off for 10 mseconds. The test was conducted for 2,210 hours, 498 Million cycles and the output power of the laser diode improved in the same manner as we see in the CW testing of the laser diodes.

A second test of our laser diodes that was performed by a third party operated a Nuvonyx laser diode high power array pulsed to 120 amps, with 500 μsecond pulses at a duty cycle of 20%. In this test the output power of each bar is 100 Watts during the long pulse. After 70 Million cycles, the Nuvonyx laser diode arrays showed no measurable degradation in power [5]. A third test is currently being performed by an independent test group; here the laser diode arrays have been continuous cycled for the last year with no degradation in performance [6]. A fourth test performed by Nuvonyx has shown that at least two primary suppliers of laser diode bars can manufacture laser diode bars that when mounted with the Nuvonyx process do not degrade any differently than CW operation, when pulsed at the thermal cycle time constant of the package (Fig. 3).

This test is still in progress and by the time of the conference the laser diodes should exceed 3,000 hours of continuous pulse testing.

6 HPDDL Paint Stripping Industrial Installation

Finally, Nuvonyx installed a high power direct diode laser system in a pulsed production paint stripping application last April. This system has accumulated over 50 million cycles during the last year for a total on time of 1100 hours with no degradation in performance.

7 Conclusion

We discuss several of these applications in which the Nuvonyx HPDDL have been implemented and demonstrate fast paybacks in harsh production environments. The predicted disadvantages of short production life times of the laser bars and laser head of the HPDDL have not been seen with the Nuvonyx ISL-4000L. The HPDDL has distinct and quantifiable advantages over traditional industrial lasers such as CO2 and Nd:YAG and non-laser technologies such a TIG, MIG, and plasma for each of these production application. These production applications are laser hardening, laser wire-feed welding, laser paint stripping.

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