NSRP ASE

"Final Report II"

FOR

Development and Commercialization of Laser Assisted Oxygen (LASOX™) Cutting for Thick Steel Sections

MARITECH ASE
TECHNOLOGY INVESTMENT AGREEMENT #2001-359

BENDER SHIPBUILDING & REPAIR CO., INC.
ALABAMA LASER SYSTEMS
BOC GASES

Table of Content

1 SUMMARY

The LASOX process is being developed to enable the cutting of thick steel, (50mm min, possibly up to 100mm) using a relatively low laser power (less than 2kW). The LASOX process is an exothermic burning reaction in which the heat of the laser beam is used to bring the steel to ignition temperature, and a specially designed nozzle is used to deliver a supersonic stream of oxygen to the heated spot, resulting in ignition and then sustained burning.

2 PROJECT RESULTS

2.1 Overview & Recap

The LASOX project was signed into contract on September 28, 2001. The first Phase of the project was a non-funded Phase 0, during which BOC Gases and Alabama Laser Systems were required to work out their licensing and intellectual property agreements. Technical work on the project actually began following a kickoff meeting in February, 2002. At this time an initial visit was made to Electric Boat to assess the feasibility of installation on their ESAB system.

Initial development work progressed at a rapid pace at ALS, with successful lab demonstrations by the middle of the summer, and installation of an alpha unit at Bender in November, 2002. In March, 2003 a visit was made to Caterpillar to firm up their participation as a second installation site. At that time there was no indication that Caterpillar would not participate, and effort was expended by all team members to assess their system, make necessary changes to their gas delivery, and build a second head.

Meanwhile, Bender continued to use the LASOX alpha system, and installed beta system upgrades to correct some of the issues raised during initial testing and production cutting. From that period through mid summer 2003 Bender used LASOX for all plate cutting requirements over 1". This included components for a crane barge, platform supply vessel components and yard needs such as lifting pads and padeyes. Pictures have been provided in previous reports of many of the components cut using LASOX.

During the summer of 2003 both Caterpillar and EB informed Bender of their decisions not to continue as participants in the project. Caterpillar provided no sound technical reason, and expressed no interest in the continued development of the technology. It is the understanding of the team that a reorganization at Caterpillar resulted in their withdrawal from the project, as the project "champions" were transferred to different parts of the organization.

Electric Boat could not come to agreement with ESAB on making the necessary modifications to their system to incorporate LASOX, and provided some valid technical constraints such as z-axis height and constraints on table modification which precluded them for continuing as a second installation site.

However, EB has expressed an interest in the continued development of the process, with an eye towards a future fiber laser retrofit of their oxy-gas cutting systems.

Technical issues identified in Section 3 suggested a need to further develop, improve, and test the LASOX system to make it more production friendly. This research and development work was performed between November 2002 and March 2005 suffering a number of major project setbacks including; 1) the loss of project team members Caterpillar & General Dynamics Electric Boat, 2) the relocation of Alabama Laser Systems testing laboratory, and 3) the loss of the project manager from the lead shipyard, Bender Shipbuilding

The project team asked for a redirection of the remaining funds, including funding that was targeted for Caterpillar and EB installations, to resolve the remaining outstanding technical issues and complete the project with a commercially viable system.

Alabama Laser Technologies & Bender Shipbuilding met, reformed, and mapped out a project plan in May 2004, to resolve the remaining issues within the revised project restart. The remaining portion of the project was split into three phases (identified in Section 3) for completion by mid April 2005.

By October 2004, Alabama Laser had chosen the method of using a fiber laser over the CO_2 laser due to the flexibility & availability of the fiber laser for experimental testing. Due to the fact that the piercing is a very aggressive process and the experiment conditions are extremely explosive, Alabama Laser Systems fabricated a protective enclosure for testing purposes and manufactured nozzles for use with the fiber lasers. Below are pictures of the Fiber Laser Head and Set Up. Below are pictures of the Fiber Laser LASOX Head and IPG Fiber 1.7kW Laser used to perform the experiments with the piercing techniques.

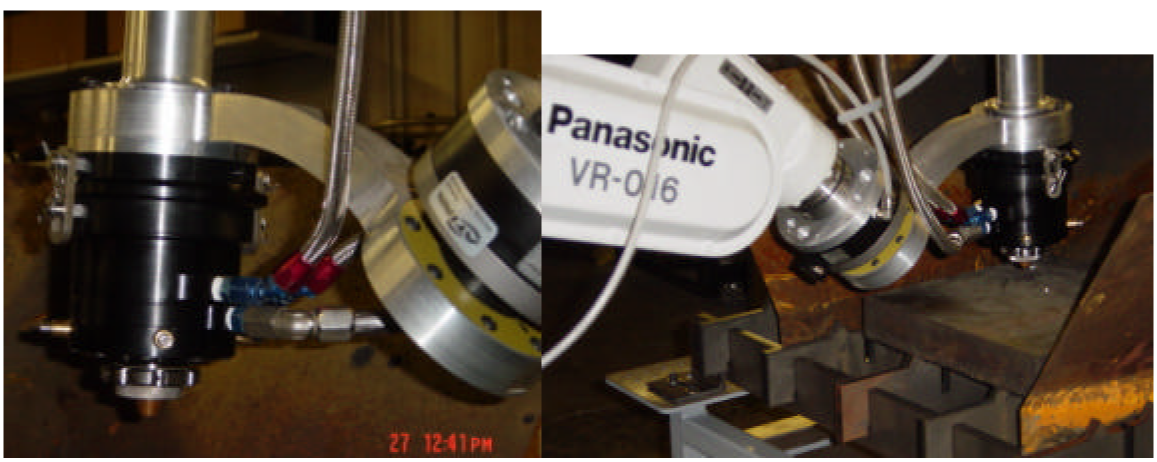


Figure 1: Fiber Laser Head

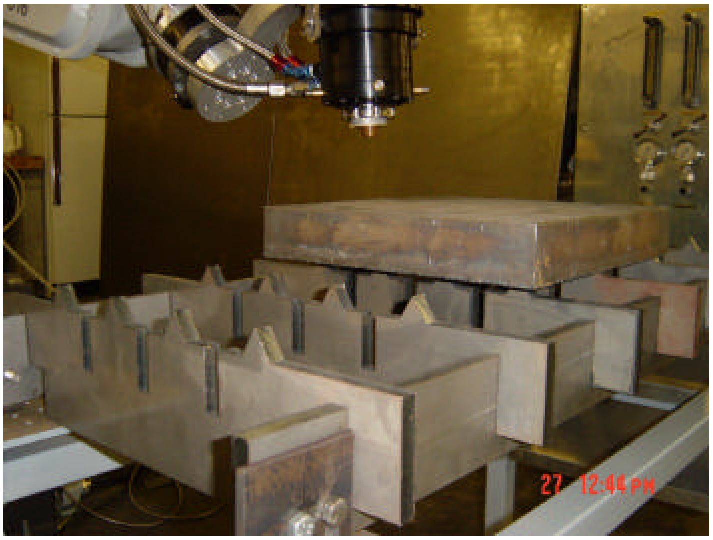


Figure 2: Fiber Laser Set Up With Thick Steel
Figure 3 Fiber Laser equipment setup

Due to the fact that the piercing is a very aggressive process and the experiment conditions are extremely explosive, Alabama Laser Systems built a protective enclosure for testing the technical issues that will be discussed in Section 3.

Figure 4: Robot w/LASOX Head and Protective Enclosure

3 TECHNICAL ISSUES

During the course of Bender's use of LASOX several major technical issues were identified that make the system less than production friendly. Until these issues were resolved, the process remains operator intensive, and required the laser operator to remain on the operator's stand during the entire LASOX evolution, and also required extensive operator intervention before and after piercing evolutions. In addition, the previous piercing solution is potentially damaging to the laser gantry. The issues are detailed in Sections 3.1 – 3.3.

3.1 Piercing Techniques

3.1.1 Vibration

There were two major issues with piercing that must be resolved. The first issue was the motion technique used to pierce thick plate. The technique, which involves moving the laser beam in a rapid circular motion while initiating the pierce, worked fine on small laboratory equipment using screw drives and electromagnetic motors. However, on a large gantry system using rack and pinion drives, the rapid circular motion must be simulated with a series of small, rapid x and y movements, essentially moved the laser beam in a small square. These motions caused excessive vibration in a large gantry, and were potentially damaging to the encoders on the equipment. The fear of damage is such that the operators stopped using LASOX piercing, and would only do edge starts.

3.1.2 Nozzle Damage

The second major issue with piercing was the nozzle damage that occurs from the high volume of slag that is ejected from the pierce hole by the high-pressure oxygen stream. Because of the small offset distance between the nozzle and the plate during piercing, the slag tends to bounce back and adhere to the nozzle, resulting in damage to the supersonic nozzle profile. The initial solution was to apply a non-stick grease to the nozzle before every pierce, which required operator intervention on every pierce. This significantly increased the total process time for LASOX cutting, and prevented the process from being run in a continuous NC program for multiple parts.

3.1.3 Proposed Solution

The proposed solution to the piercing problem involved a return to basic R&D in the design spiral. The issue could not been quantified until the system was run in a production mode, so it could not have been adequately addressed in the initial LASOX release.

Preliminary investigation into possible solutions led to a proposed 2-step approach. The first step was to revisit the nozzle design itself. The initial design was an extension of normal laser cutting tips, with an internal LASOX profile. The design offered a large surface area for slag adhesion during piercing. ALS proposed investigation of a longer, slender profile tip that would offer a very small diameter **profile to any spatter.**

The second part of the proposed solution was to use a gas pressure ramping technique during piercing, similar to what is done with oxy-gas piercing. Parameter development required some lab work, followed by production testing.

3.1.4 Piercing Techniques Tested

The major issue centered on the piercing techniques came from the "blast" of the pierce. The molten steel material that was displaced during the piercing process was jetting back up into the copper nozzle and embedding itself into the nozzle. Up until the end of the first installation of LASOX, the piercing techniques only explored use of a shielding plate that concentrated on shielding the nozzle. It was determined after the initial LASOX installation that additional piercing techniques needed to be identified due to the continuous and numerous piercing could not be accomplished. There were ten additional LASOX piercing techniques identified. Not all techniques were tested due to various reasons and constraints. The ten LASOX piercing techniques are identified and listed below:

1. Small Graphite Shield – Examined & Tested
2. Big Graphite Shield – Examined & Tested
3. Carbide Nozzle – Lead time development was not sufficient
4. Titanium Nozzle – Examined & Tested
5. Long Focal Length Lens - Lead time development was not sufficient
6. Oxy Fuel Gas Jet – Lead time development was not sufficient
7. Gouping Nozzle – Examined & Tested
8. Inconel Nozzle – Examined & Tested
9. Special Coated Nozzle – Examined & Tested
10. Piercing with aid of Side Jet – Examined & Tested

3.1.4.1 Small Graphite Shield

The initial experiment tested used a small graphite shield to protect the LASOX tip from the effects of splatter during the piercing operation. The design took a standard copper tip that was modified to suit the graphite shield, which is press fitted to protect the nozzle as shown in the photos below.

Figure 5: Graphite Shield with Copper Tip

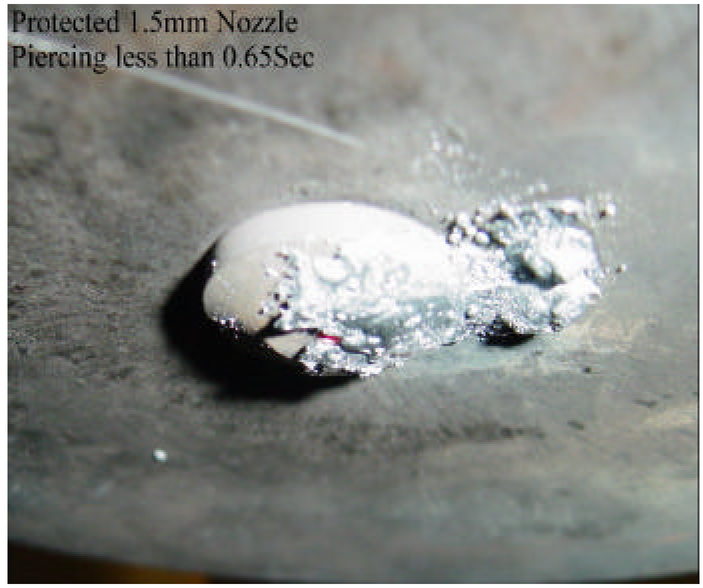
Figure 6: Graphite Shield Cross-Section

A series of piercing experiments were carried out and the best condition yielded the following results:

Nozzle dia	1.5 mm
Material thick	25.4 mm
Laser Power	1500 W
Oxygen	140 PSI
Stand off	4.7 mm
Piercing Time	0.65 Sec

Figure 7: Pierce holes using Small Graphite shield

Figures 8 & 9:Additional photos of the pierce hole experiments (best conditions) using the small graphite shield.



The graphite shield was able to prevent the adhesion of splatter to the copper nozzle, but the shield came off from the nozzle due to thermal expansion, there by preventing continuous piercing test. Even when the graphite shield was glued to the nozzle, due to thermal expansion, the shield came off and prevented continuous piercing experiments. The conclusion of the experiments led to the necessity of a new shield design with an improved holding mechanism for adhesion to the copper nozzle.

Figures 10 & 11: Fallen Small Graphite Shield

3.1.4.2 Big Graphite Shield

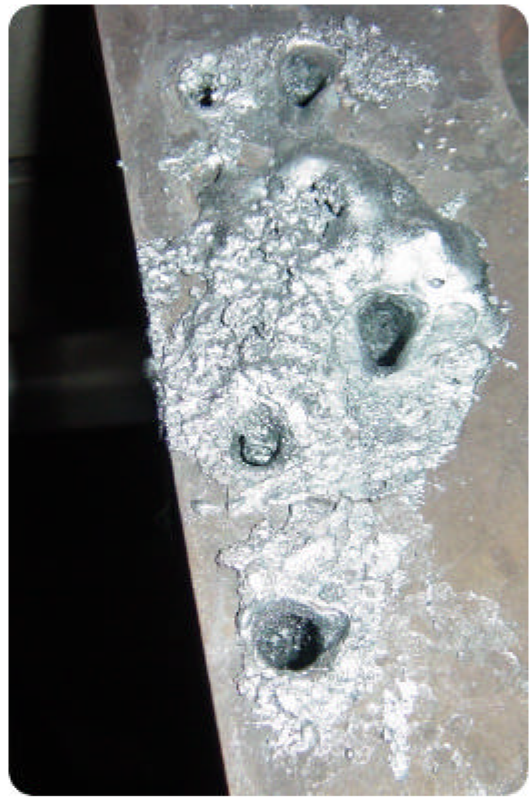
The second experiment used a big graphite shield to protect the LASOX tip from the effects of splatter during the piercing operation. The design took a tip holder nut that was modified to suit the graphite shield, which was held by screws to prevent the shield from falling off as shown below.

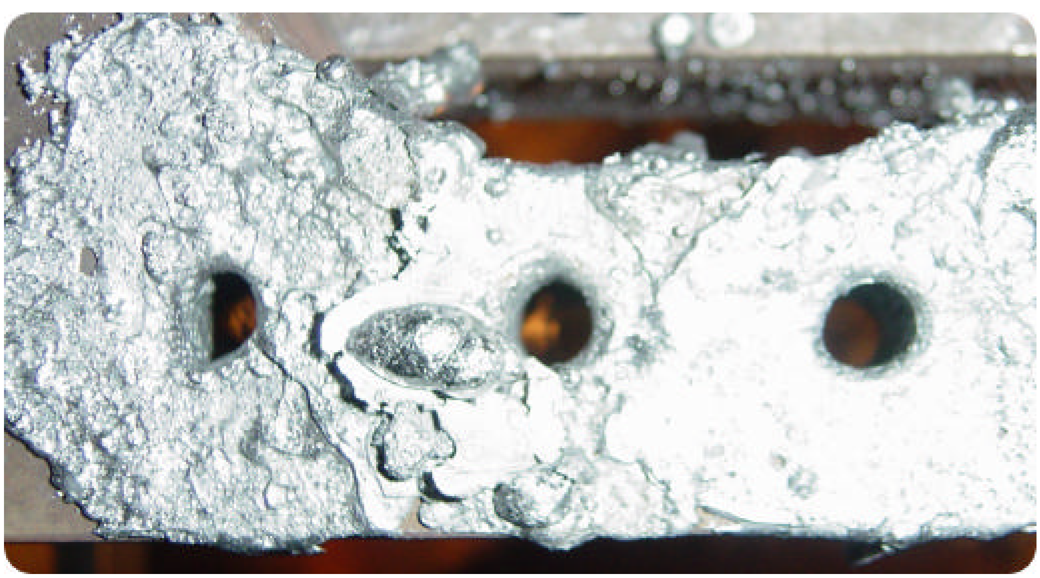
Figure 12: Big Graphite Shield Isometric View

Figure 13: Big Graphite Shield with screws

A series of piercing experiments were carried out to validate the design. The parameters were:

Nozzle dia	1.5 mm
Material thick	38.5 mm
Laser Power	1500 W
Oxygen	140 PSI
Stand off	4.0 mm
Piercing Time	3.0 Sec





Figures 14 & 15: Pictures of the pierce holes

The graphite shield was able to prevent the adhesion of splatter, and the big shield did not come off, thereby validating the holding mechanism.

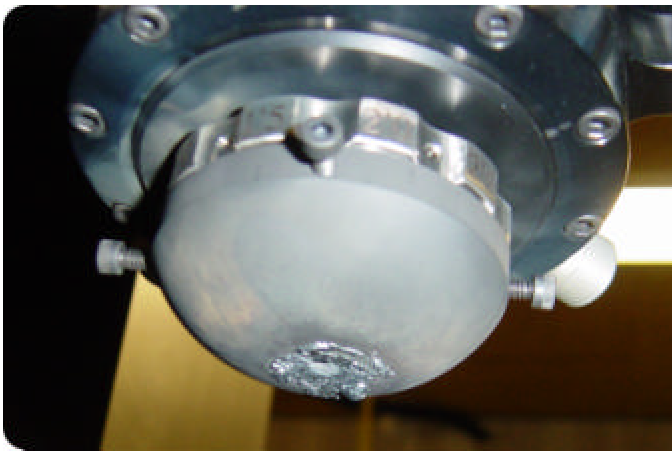



Figure 16: Big Graphite Shield after piercing
Figure 17: Big Graphite Shield /screws after piercing

However, a thin section around the nozzle face was eroded off during repeated piercing test making the nozzle vulnerable. The experiments led to the conclusion of the necessity of increasing the graphite thickness around the nozzle face and explore other possibilities for future development.


Figure 18: Big Graphite Shield with eroded tip
Figure 19: Big Graphite Shield/screws and eroded tip.

3.1.4.3 Carbide Nozzle

The carbide nozzle provides a greater wear resistance and high thermal properties. This piercing technique was explored to incorporate the nozzle as a core insert or as a complete nozzle tip. The graphite used in the previous testing prevents adhesion of splatter, but the nozzle made of graphite is quickly eroded at the throat. The carbide nozzle was a proposed solution but the lead time for development was not sufficient and was not examined or tested.

3.1.4.4 Titanium Nozzle

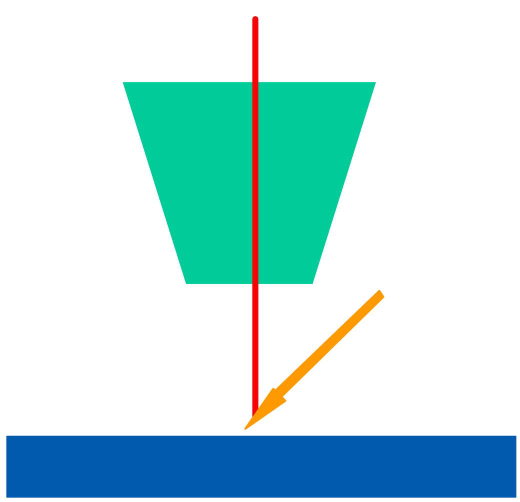
The titanium nozzle provides a higher melting point, about 200 degrees C, above carbon steel. Titanium also has well anti adhesion properties, and it was expected that the steel splatter would not adhere to the nozzle and the shield design. This process was tested and yielded potential fire hazards and deemed “not viable” for piercing.

3.1.4.5 Long Focal Length Lens

The long focus lens piercing technique was considered in possibility of a long focus lens, where a greater field of depth would be used, the head could stand far off and miss the piercing splatter. Currently the piercing process uses a 50mm-focus lens at a stand off distance possible is only 4mm to 5mm. However, gas dynamics needed to be tested, at various standoff distances, to nail the optimum distance and focus lens combination. The Long Focal Length Lens was a proposed solution but the lead time for development was not sufficient and was not examined or tested.

3.1.4.6 Oxy Fuel Gas Jet

The oxy fuel gas nozzle provides the option of an external oxy fuel gas nozzle to deliver oxygen at the laser spot, at an angle instead of perpendicular to the surface. During the piercing process, a trench effect would be made and the splatter would not rise up into the nozzle (as shown in diagram below). However, the lead time for development of the Oxy Fuel Gas Jet was not sufficient and was not examined or tested.



3.1.4.7 Gouping Nozzle

The gouping nozzle technique was an enhancing application that was explored in efforts to protect the LASOX tip from the effects of spatter during the piercing operation using anti-spatter grease. The design considered the standard copper tip that was brushed with a thick coat of anti-spatter grease. In the efforts to prevent damage of the LASOX head from the spatter, a 2.5" diameter graphite shield (as shown in Figure 20) was used.

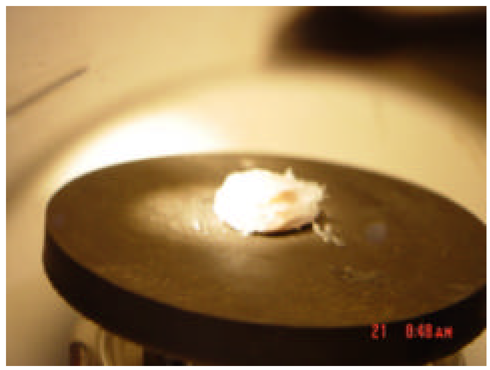


Figure 20: Gouping nozzle with anti- spatter grease.

The spatter adhering during incomplete piercing was easy to brush off without any damage to the nozzle. Figure 21 shows the copper nozzle after a series of pierces.

.

Figure 21: Copper nozzle with anti-spatter brushed off after a series of pierces

In conclusion, the nozzle survived the piercing, even when the piercing hole was not completely cut through the material. The gouping process was validated and a more automated process was explored to do away with the manual gouping process. A manual gouping process would require an application of the anti-spatter gouping to be applied to the nozzle at each piercing. In order to make the process more production ready, a design was explored for a mechanical arm to ride in the carriage of the Tanaka Laser Gantry. This would allow the arm to travel from the LASOX cutting head to a container housing the anti-spatter gouping between piercing. The mechanical arm would be programmed to apply the anti-spatter to the tip of the nozzle, return to the container housing the anti-spatter gouping, dip the cup to apply the anti-spatter gouping for transfer back to the LASOX piercing nozzle to apply the gouping for the next programmed piercing process. In the end, this process was not developed due to other piercing techniques examined.

3.1.4.8 Inconel Nozzle

The Inconel nozzle technique tested a nozzle made with Inconel, a better choice over graphite nozzle and safer compared with the potential fire hazard using the titanium nozzle. Figures 22 & 23 provide the results from one pierce.

Figure 22 - Inconel nozzle prior to pierce.

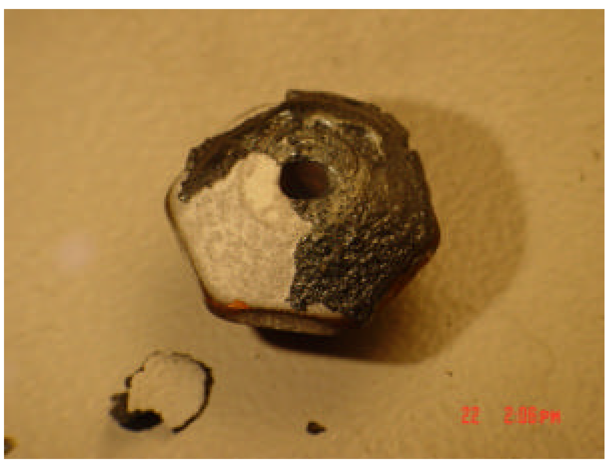
Figure 23 – Inconel nozzle after one pierce.

In conclusion, the Inconel tip did not survive even one pierce. The melting point was lower compared with steel and not suitable for the LASOX process.

3.1.4.9 Coated Nozzle

The Coated nozzle technique was tested to evaluate a temperature resistant coated nozzle. The nozzle lasted piercing on a couple of holes that were made. During the first few pierces, the removal of the adhered spatter was no problem. After which, the process revealed that the coating had been chipped away while removing the adhered spatter as shown in Figure 24 & 25 below.

Figures 24 - Coated nozzle prior to pierce.



Figures 25 - Coated nozzle after a few pierces.

In conclusion, the coated nozzle survived a few pierces, but the spatter succeeded in damaging the coating on the nozzle. It was determined that the possibility of combining this technique with the "side air jet technique" to assist in pushing away the piercing spatter could potentially allow the nozzle to last longer.

3.1.4.10 Side Air Jet

The side air jet is a technique to direct air surrounding the LASOX process to form a curtain, so that the molten metal is pushed away from the nozzle tip. During the piercing process or when piercing fails, splatter raises up to touch the nozzle and the shield. This technique is anticipated to be a necessity in the long run. Design is underway to position the nozzle without causing any effect to the LASOX gas stream. This process was developed due to its anticipated importance for the future application and possible enhancements that could be made in using this technique in conjunction with other piercing techniques.

3.1.4.10.1 Quick Test #1

The first quick test was performed in the effort to examine the process with a regular LASOX copper nozzle (without a graphite shield), using shop air to shield the spatter. Figure 26 shows the setup.

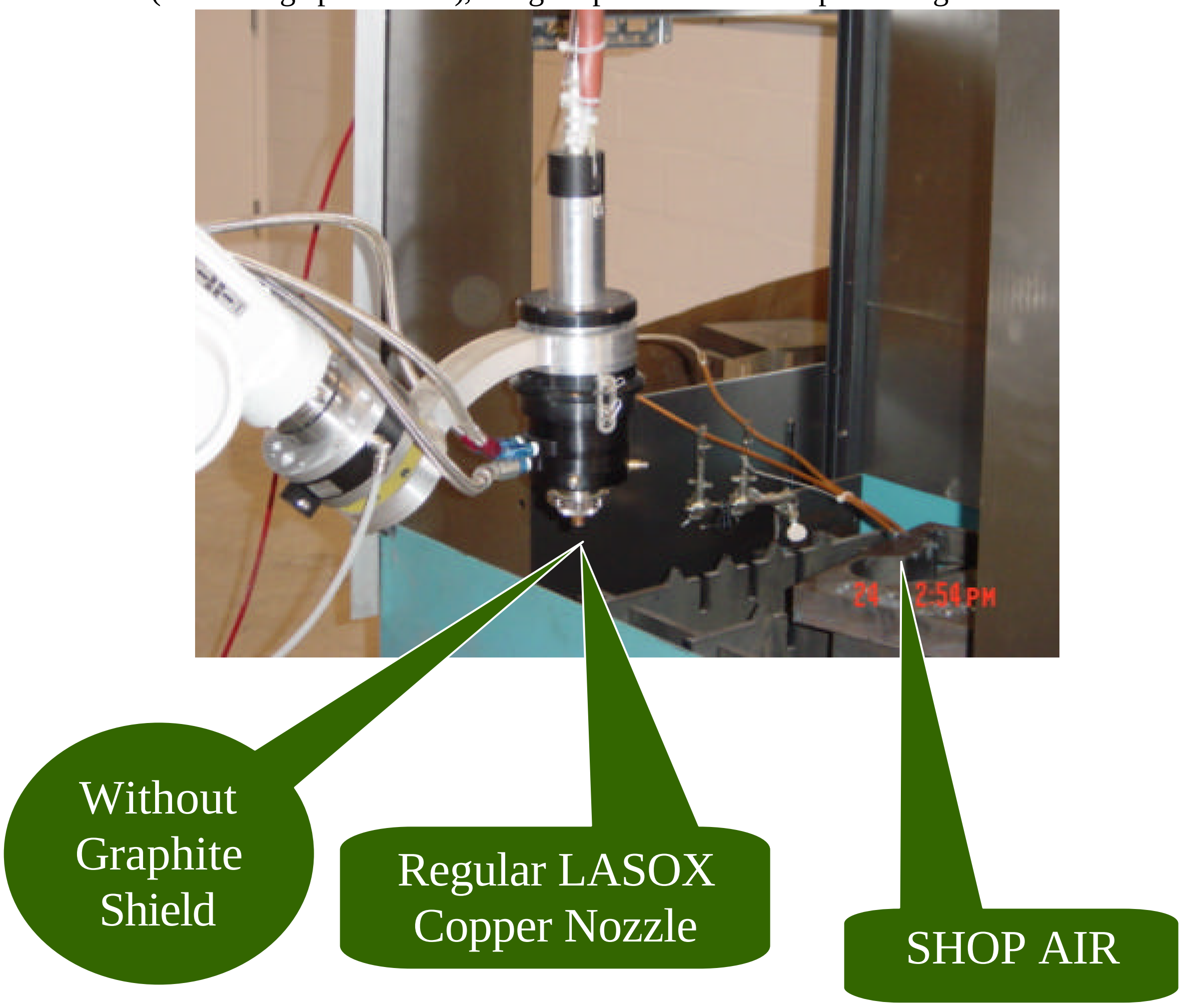


Figure 26: Quick Test #1 set-up

The results from the quick test #1 pierced holes through on 1-1/2" thick material, however the technique left no spatter on the nozzle after piercing. The setup survived many failed pierces but, in the same, validated the approach. Table #1 provides the parameters used in the test. Figures 27 & 28 show partially pierced holes from the test.

Nozzle dia	1.5 mm
Material thick	38.1 mm
Laser Power	1500 W
Oxygen Pressure	140 PSI
Stand off	4.35 mm
Piercing Time	1.5 Sec ~ 2.25 Sec

Table 1: Quick Test #1 piercing parameters

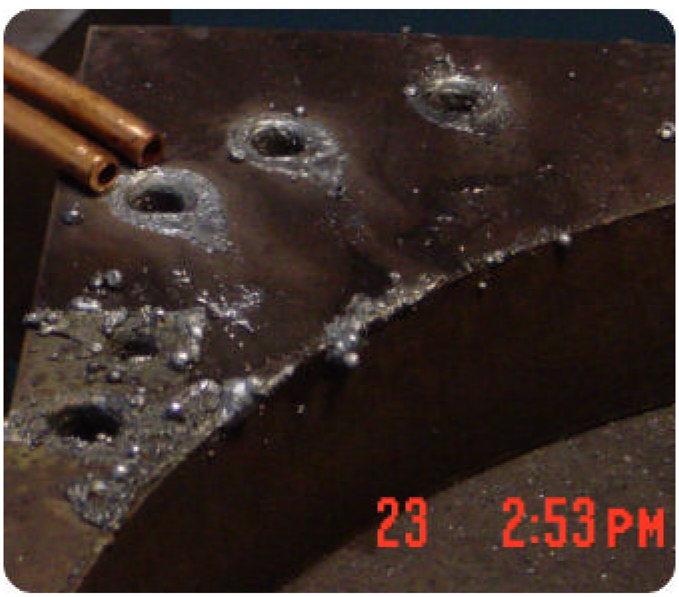


Figure 27: Quick Test #1 partial piercing holes

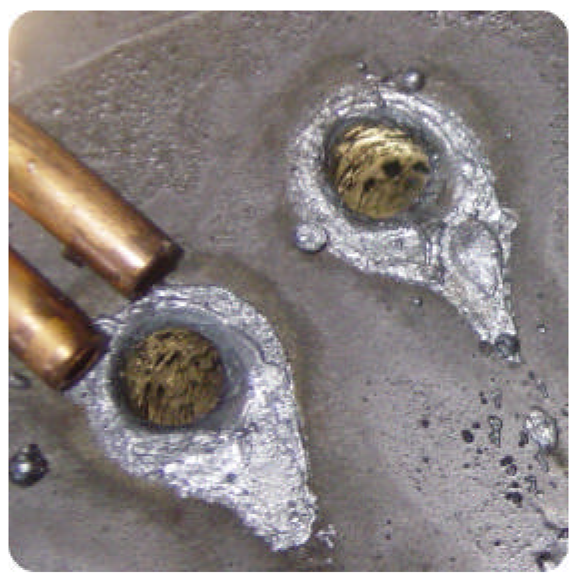


Figure 28: Quick Test #1 partial piercing (close-up)

3.1.4.10.2 Quick Test #2

The second quick test was performed suspecting the air jet poisoned the piercing gas jet. Oxygen was used as the side jet instead of the shop air in the previous test setup. The results from the 2^{nd} quick test revealed that the hole pierced through and had a spout appearance on the top face. Figures 29 & 30 show the spout from the pierce. It was determined that the oxygen coming from the side jets caused excessive secondary burning, and oxygen should not be used in the side jets.

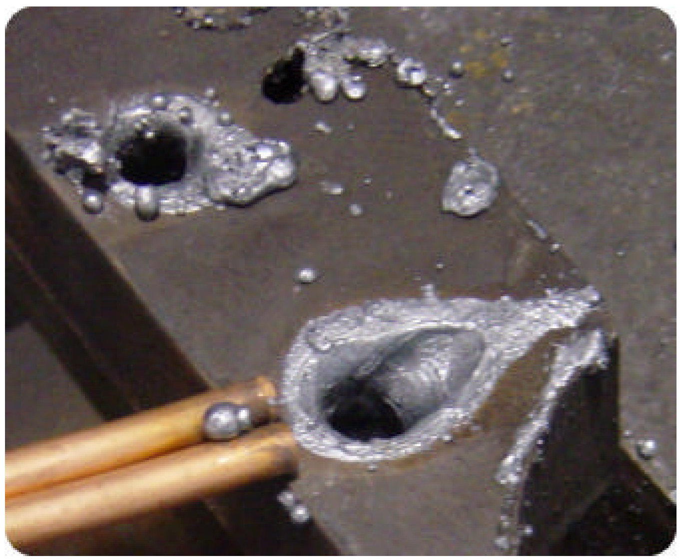


Figure 29: Isometric view of spout from pierces

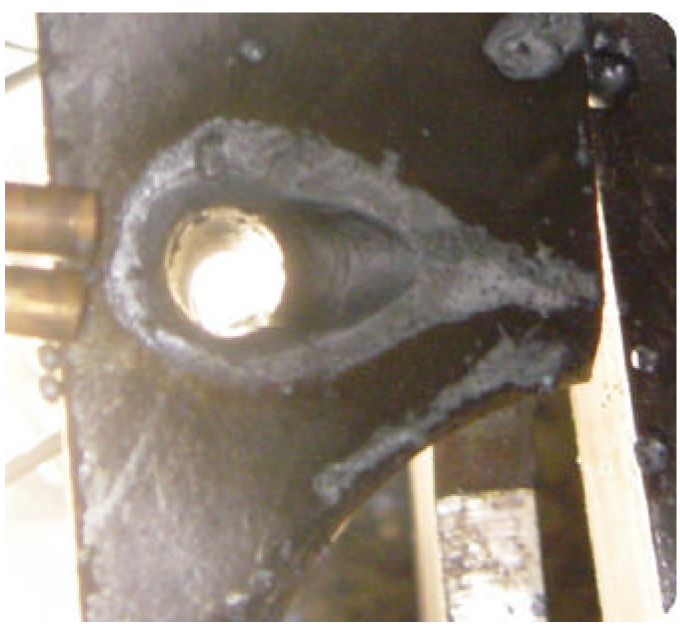
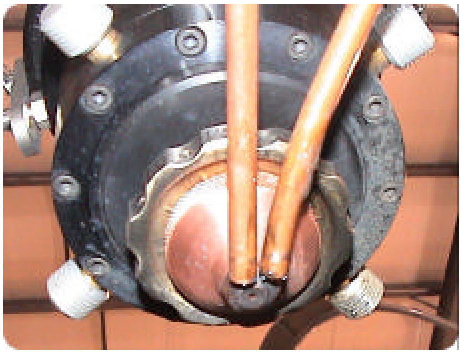


Figure 30: Top view of spout from pierce

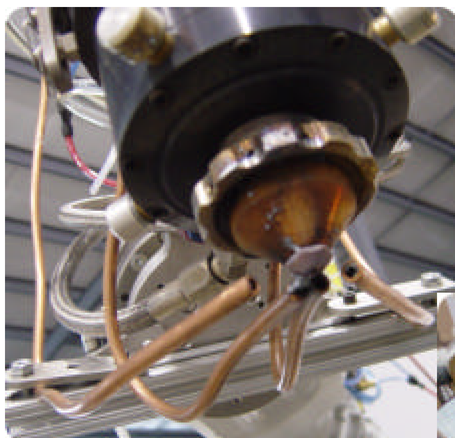
3.1.4.10.3 Quick Test #3

The third quick test performed was to find the size and quantity of side air jets required. Figures 31-33 shown below provide the three different scenarios tested.



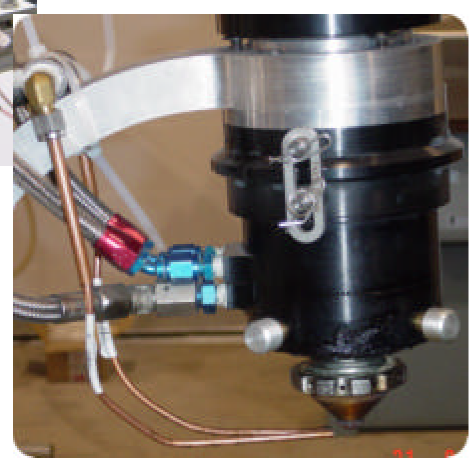
¼” – 2 jets

Figure 31



¼” – 4 jets

Figure 32



5/32” – 2 jets

Figure 33

The results from the 3rd quick test determined that two streams from side air jets are required to carry out the process. The air stream from the 5/32" size tube is sufficient for the process, but there needed to be a process to easily clear or prevent material buildup on the top surface after piercing.

3.1.4.10.4 Quick Test #4

The forth-quick test was performed in the effort to prevent or clear the material buildup on the top surface of the plate being pierced. An anti-spatter spray was applied manually (with a spray bottle) on the top surface of the material to prevent sticking. Additional air steams were used at first, but they did not lend themselves helpful in the testing. The results from the 4th quick test yielded 21 continuous pierced holes with little to no build up of displaced material left on the top surface as shown in Figure 34.

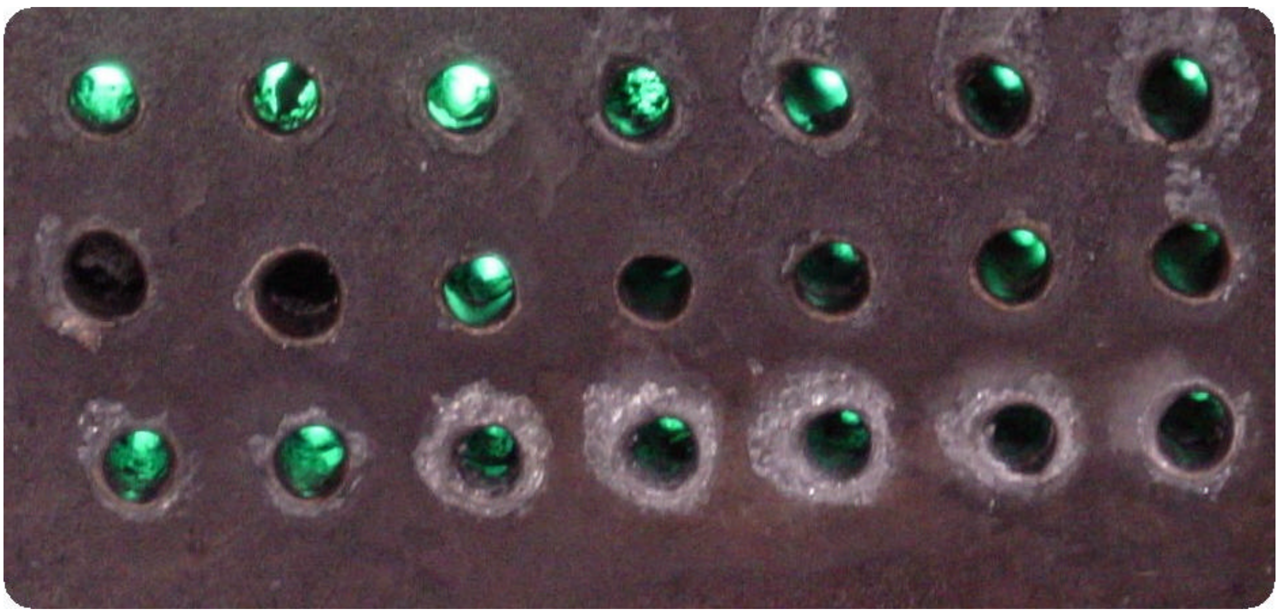


Figure 34 Top view of the 21 continuous pierced holes made with the anti-spatter application using the side air jet piercing technique.

In conclusion, the nozzle survived the piercing, even when the hole did not penetrate the material and validates the side air jet piercing process. There is a need to automate the anti-spatter spray application and methods to hold the solution in a reservoir that can be mounted onto the Tanaka Laser gantry are being explored for installation. A robust side air jet assembly with proper cooling and adjustment mechanism needs to be designed and incorporated into the process. The experiment also revealed material that is climbing up to the head, where the incorporation of a couple of air knifes would prevent this.

Gas Control

3.1.5 Manual Operation

The first installation of the LASOX system used a manually operated ball valve to turn the high-pressure oxygen on and off. This had to be done at every pierce (further amplifying the piercing problem) as well as at the initiation and completion of every cut. See figure for example:

Figure 35:**Manual operated ball valve LASOX oxygen gas control assembly**

An analog gas control valve was identified, purchased and tested, but during installation at Bender a controller interface issue was identified (concern that a feedback signal would fry the CNC controller) which precluded the use of the valving system at Bender. Since that time the circuits were tested and the concern mitigated, thus the development moved ahead to integrate a gas control for LASOX.

3.1.6 Proposed Solution

The proposed solution was to complete the installation of the gas control valve at Bender Shipbuilding and program the CNC ladder with the valve operations during LASOX cutting and piercing. This effort had been delayed due to the piercing issue described above, because the CNC programming and the use of spare interfaces is completely dependent on the need (or lack thereof) to ramp the gas pressure during piercing.

3.1.7 Gas Control Integration

As stated in previous reports and briefings, the original LASOX concept did not incorporate the use of analog gas controls; so piercing has been accomplished in a "blast" mode, with full gas pressure and flow applied instantaneously. One of the issues associated with the piercing technique comes from the "blast" of the pierce. It was anticipated after the first installation on the Tanaka Laser at Bender Shipbuilding, that the ability for the machine to control gas flow was a critical feature in providing a production ready system. Efforts to automate the delivery of oxygen gas for the LASOX process and eliminate the need of manual gas on/off valve and the associated labor have been accomplished.

The design of the gas control considered a pierce rate regulator assembly for oxygen service. Figure 36 provides a photograph with component labeling of the LASOX oxygen gas control assembly. The assembly was designed to:

1. Provide oxygen needed for the LASOX process.
2. Vary the rise time needed to accomplish piercing.
3. Stop oxygen flow after piercing.
4. Be controlled by M codes, to eliminated manual labor.

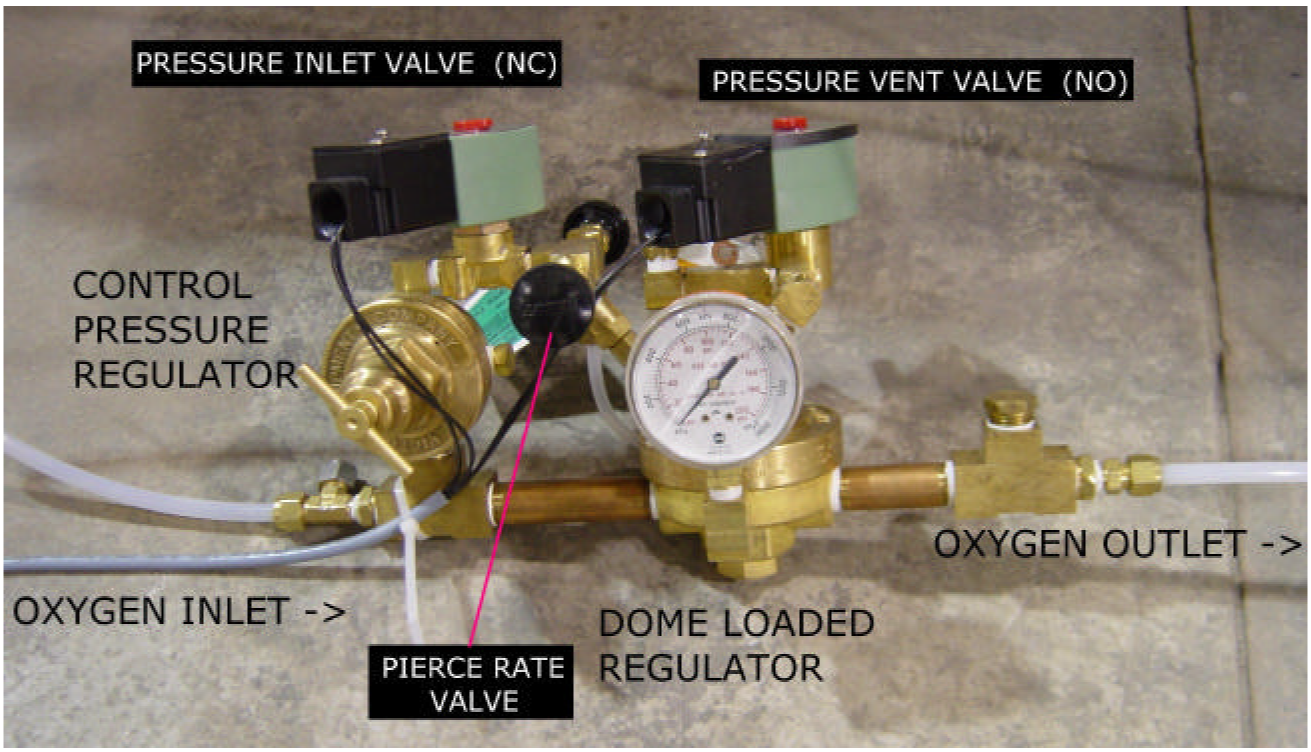


Figure 36: Labeled LASOX oxygen gas control assembly

The control pressure regulator is used to set the final output pressure of the pierce rate circuit. The pierce rate valve is used to set the rate of pressure increase. The dome-loaded regulator contains a certain amount of empty volume that is charged as per the setting of the pierce rate valve, when activated. The dome regulator sets output pressure to match the slowly rising control pressure. The pressure vent valve dumps the control pressure at the end of the cycle, so that the dome-loaded regulator closes quickly and outlet pressure drops back to zero. The system is activated by two M-Codes from the controller.

The gas control circuit was used to pierce a dozen holes at 100psi oxygen pressure in a1-1/2 inch (38.1mm) thick slab. Previously the process required an operating pressure of 140psi for LASOX piercing. The gas control performed perfectly in the piercing of thick slabs in the ALS test laboratory.

Figure 37 is another photograph of the assembly circuit that was used in the installation at Bender Shipbuilding.

Figure 37: Photo of the LASOX oxygen gas control assembly

Two M-Codes were needed on the Tanaka Machine for installation and automation of the gas control assembly at the time of installation. A preliminary installation visit by ALS and the laser operators of the 6kW Tanaka Laser at Bender Shipbuilding, revealed the availability of the two M-Code ports that can be used to control the gas assembly. These controls were integrated into the Fanuc control program and machine itself to initiate the LASOX process as shown in Figure 38 below.

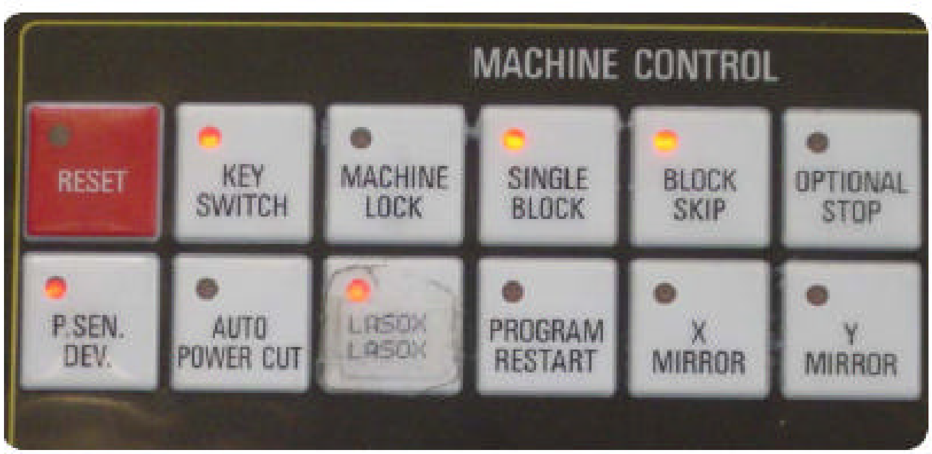


Figure 38: Photo of the LASOX key pad control button

3.2 Height Sensing

3.2.1 Capacitive Sensing Issue

Conventional laser cutting uses a capacitive sensing method in which an impressed current between the tip of the nozzle and the plate is measured by the machine controls, and the z-height of the nozzle tip is maintained at a constant height by maintaining a constant current. This is somewhat similar to the arc voltage controls used in plasma cutting. The issue with LASOX is that the offset distance between the nozzle and the plate is almost 5 times greater than with conventional cutting, which renders the existing capacitive sensing system inoperative. Without capacitive sensing the LASOX operator has to constantly watch the tip of the cutting nozzle, and manually adjust the height up or down to compensate for variations in the flatness of the plate. This process is simply not acceptable in a production environment, and the initial assumption that thick plate would be sufficiently flat to not require height sensing was incorrect.

3.2.2 Proposed Solution

Alabama Laser had been working on a height sensing solution that works using a magnetic field sensor. The system was proven to work on their lab system, but the system had yet to be integrated with the Tanaka system, or tested in production. The LASOX system could be installed and tested after the piercing and gas control issues are resolved without the height sensing capability. Until those issues were resolved, in that order, there was little sense in putting further effort into the height sensing. Alabama Laser suggests a one-day effort be set-aside at the next installation for the programming effort associated with the height sensing. If a significant programming effort is called for, the separate height sensing control box will be added and tested on the Tanaka Laser system at Bender.

3.2.3 Height Sensing Integration

Initially, Alabama Laser System was to develop the programming code for the Fanuc control system and the magnetic field sensor (cable) that was needed to control the height of the LASOX cutting head. If unsuccessful, the secondary plan was to develop a completely separate height sensing control box for installation on Bender Shipbuilding's Tanaka Laser. ALS worked on both scenarios due to the fact that there were issues with both. However, the secondary effort with developing an entire separate height sensing control box went a little beyond the scope of work for this project. The expectations were centered on just making it work on the existing Precitec height sensing unit installed on the Tanaka Laser system at Bender. Figures 39 – 41 show figures of the Precitec height sensing unit connected to the normal laser cutting head.

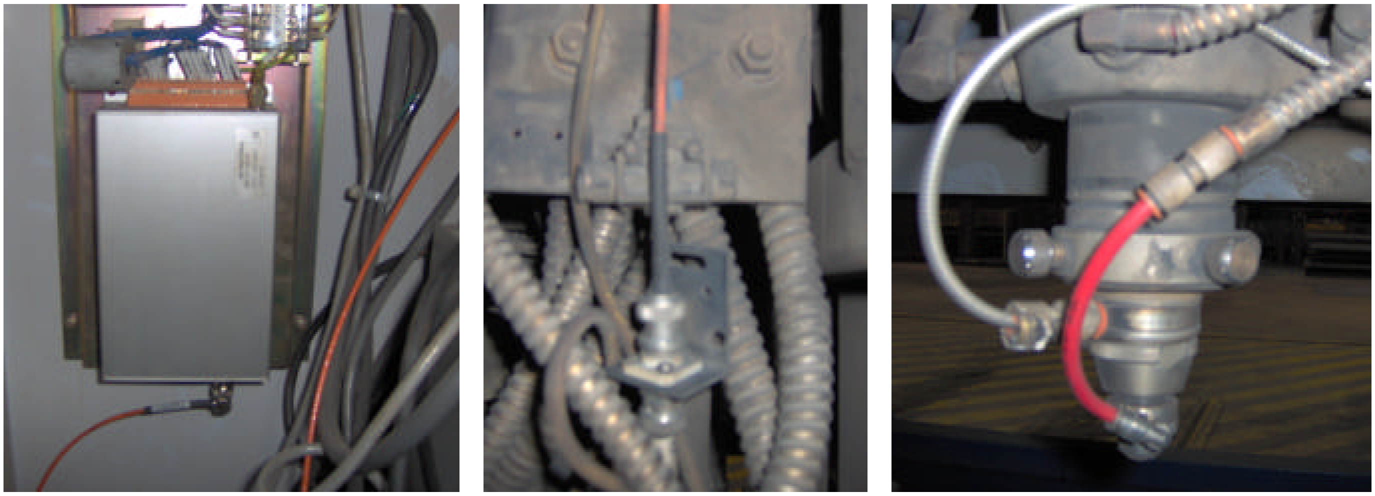


Figure 39 - 41: Photo of the Precitec Height Sensing box, cable, and connection to head.

The pre-installation visit provided ALS with enough information to develop the code needed for the Fanuc control system ladders. At the second installation at Bender Shipbuilding, two days of programming were spent by Alabama Laser as well as modifying and connected the height sensing cable. When initiated the machine only alarmed in the upwards direction. When the LASOX head moved towards the plate after execution, the head didn't stop and crashed into the material on the cutting table. So it was determined that the Precitec senor control was not able to recognize the signal generated during the sensing operation to stop the Z motion.

During the programming phase it was noted that a extensive programming effort would need to be made in the effort to tie in the new LASOX height sensing mechanism that would almost require a complete re-write of the Fanuc Control ladder program. It was determined by the project team that this was not an option and could be in violation of the maintenance agreement with Fanuc for the controller software.

Alabama Laser attempted to resolve the height sensing problems with additional fabricated height sensing gear for the LASOX head. One additional part was fabricated to isolate the nozzle assembly from the LASOX head itself. See Figure 42 that shows the isolator piece that was fabricated by ALS. It was noted at the installation that there was a voltage charge on the nozzle assembly itself and it was thought that without an isolator piece separating the head and the nozzle may cause the height sensing equipment to not work properly.

Figure 42: Isolator attached to the LASOX head

Another piece of height sensing gear was fabricated for connecting to the existing Precitec height sensing control box and the LASOX head. The height sensing cable was fabricated without a metal jacket so that no transfer of voltage would be passed to the nozzle assembly. Figure 43 shows a picture of the height sensing cable that was shipped with the isolator.

Figure 43: Height Sensing control cable

4 LASOX INSTALLATION AND IMPLEMENTATION

The second installation of the LASOX system was completed at Bender Shipbuilding on April 29th, 2005. The demonstration was held with the project PTR, other gulf coast shipyard representatives, the project team members, and other Bender Shipbuilding personnel including Mr. Bender himself. The demonstration provided a number of successful pierces that were gas controlled and fully integrated with the laser controls to test cut parts. As noted earlier, the height sensing still remains an issue in the LASOX process. ALS and Bender Shipbuilding have continued to work on new height sensing part testing in the effort to complete a production ready system. The figures below are photos taken at the second LASOX installation at Bender Shipbuilding.

Figures 44 & 45: LASOX System Installation on Bender Shipbuilding's 6kW Tanaka Laser

Figure 46: Initial test pierces made with LASOX

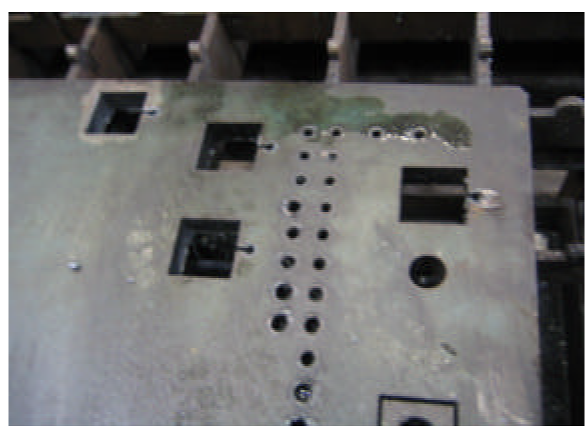


Figure 47: Initial pierces & cuts made with LASOX

Figure 48: Initial test pieces cut with LASOX

Figure 49: 1.5 inch thick test piece cut (7/8in, 1-1/4in, 1-1/2in material) with LASOX

Figures 50 & 51: LASOX System Installation in operation on Bender Shipbuilding's 6kW Tanaka Laser

To date, Bender has used LASOX for plate cutting requirements over 1" and up to 1.5" thick material. Only a few components for a ship repair vessels and yard needs such as lifting pads and padeyes due to the schedule requirements and lack of material parts needed between those thicknesses.

5 ROI Summary and Analysis

Bender received a direct benefit from this research and technology by reducing ship construction costs and improved in-house cutting capability by using high power lasers in applications that have been developed and explored on this project. By integrating process improvements with full exploitation of state of the art tools, Bender will achieve a reduction in unit cost, an increase in unit production and an increase in net profits.

Bender has experienced an immediate improvement in thick steel cutting capability with laser quality and precision without a significant new equipment investment. As other shipbuilders invest in laser cutting technology, the LASOX technology will also be available, thus combining what is now multiple cutting systems (plasma for thin sections and oxy-fuel for thick sections) into a single, system that improves accuracy and quality, while reducing operating and fabrication costs.

The direct return on investment for shipbuilding was anticipated at a 3:1 ratio due to the increased speed of cutting plate between ¾" and 1", a 5:1 return due to the elimination of extra handling and a second beveling step, and an additional 3:1 in assembly due to accuracy of the parts.

Return on Investment (ROI) is, as presented in the included ROI Worksheet. For the purposes of this project, we used the model for a small sized commercial shipyard, as done in the original proposal document. These model characteristics are as follows:

	Small Size Commercial Shipyard
Throughput	2 designs/year 5 ships/year 16K tons steel/year 90K feet of pipe/year 260K feet of cable/year
Employees	50 pre-construction staff 35 design 5 material 10 planning & production control 600 production staff 280 steel production 230 outfit production 90 paint & service production
Billing Rates	$60/hour – pre-construction $45/hour - production
Cost per Ship	$30 million per ship $18 million material $12 million labor & overhead

In addition to the conditions in the small commercial shipyard model, the following were considered in regards to return:

a. To account for full implementation time, savings are not realized until the year 2006. Development work prior to implementation of the finished system does not contribute to savings. Approximately 4 months in year 2005 will see savings realized.

b. Steel work is done for 50 man-hours per ton overall or 800,000 man-hours per year using the small shipyard model.

c. The steel work is divided along an approximately 55%-45% split for fitting and welding tasks or 440,000 man-hours annually for fitting work and 360,000 man-hours annually for welding.

d. The production hours expended on each vessel are approximately 40% steel related and 60% outfitting.

e. Thick steel work accounts for approximately 7.5% of the total steel, and 12.5% of the total steel work on a given vessel, or a total of 60,000 man-hours.

f. A 35% reduction in overall fit-up time accrues directly in fabrication and construction processes because of improved fit, new, more accurate joints (less tacking) and flatter parts and panels. This figure equals 35,000 hours savings annually or **$1,575,000** per year.

g. There is a 30% reduction in overall rework which would normally be required due to panel and part distortion (flame straightening) and errors in fit-up in all stages of construction.

h. Rework adds an additional 8% to the overall man-hours for a vessel's construction and approximately 25% of those hours are fitting related. This equals approximately 9000 man-hours total, of which 12.5%, or 1125 hours, are related to thick steel. This is an additional savings of **$50,625.00** per year.

i. Steel drop is approximately 20% of overall steel weight. On 16,000 tons of steel going into the ship, approximately 1000 tons are thick steel, with an additional 300 tons required for drop. Improved nesting capabilities possible through LASOX accuracy and lower heat input allows for a 20% reduction in steel waste (drop) that equals 60 tons.

j. At current steel price at approximately .46 per pound (on a warehouse order), with added surcharges around $75 per ton, the 60 ton drop reduction saved equals $55,200 in material savings and $4,500 in surcharges for a total of **$59,700** annually.

k. Sales of LASOX systems at **$300,000** per year. Sales of systems should number 6 per year for at least 10 years. Given a $672,000 investment, and a $50K selling price for the system hardware and software, 60 systems over 10 years results in over a 4:1 return.

l. There is a direct savings, which accrue to repair efforts. A continuing repair effort throughout the year accounts for approximately 50% of the steel man-hours dedicated to new construction. 12.5% is attributable to thick steel work. This equals 50,000 man-hours per year. Only a 15% reduction in fitting and a 2% reduction in welding occur because of the more difficult environment in applying laser cut parts effectively into repair jobs. This results in an annual savings of 3,750 hours in fitting and 500 hours in welding. Total savings = 4,250 man-hours or **$191,250.00** per year.

5.1 ROI WORKSHEET

Project Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Program Funds requested from Cost Proposal (i.e., Investment)	154,116	182,063	182,063	76,878	76,878	0	0	0	0	0
Recurring Costs	0	0	0	0	0	0	0	0	0	0
Present Value of Investment	154,116	165,514	150,457	57,759	52,508	0	0	0	0	0
Savings					605,758	2,341,995	2,341,995	2,341,995	2,341,995	2,341,995
Labor (Direct & Indirect)					472,500	1,575,000	1,575,000	1,575,000	1,575,000	1,575,000
Maintenance										
Rework					15,188	50,625	50,625	50,625	50,625	50,625
Scrap					17,910	59,700	59,700	59,700	59,700	59,700
Services										
Equipment										
Inventory										
WIP										
Material & Supplies										
Schedule										
Cost Avoidance					57,375	191,250	191,250	191,250	191,250	191,250
Time Value of Money					42,786	165,420	165,420	165,420	165,420	165,420
Additional Income						300,000	300,000	300,000	300,000	300,000
Other										
Present Value of Savings	0	0	0	0	413,733	1,454,145	1,322,056	1,201,912	1,092,541	993,240
Net Benefit	-154,116	-182,063	-182,063	-76,878	528,880	2,341,995	2,341,995	2,341,995	2,341,995	2,341,995
Present Value of the Net Benefit	-154,116	-165,514	-150,457	-57,759	361,225	1,454,145	1,322,056	1,201,912	1,092,541	993,240
Discount Factors	1.00	0.91	0.83	0.75	0.68	0.62	0.56	0.51	0.47	0.42
Cumulative Present Net Value	-154,116	-319,630	-470,087	-527,846	-166,621	1,287,524	2,609,580	3,811,491	4,904,032	5,897,272

Net Present Value	5,897,272	The method chosen to represent ROI for NSRP ASE ranking purposes. Equal to the Cumulative Present Net Value at the end of the 10 year period.