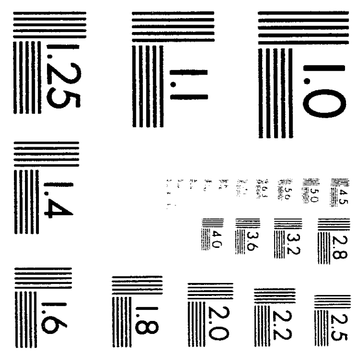
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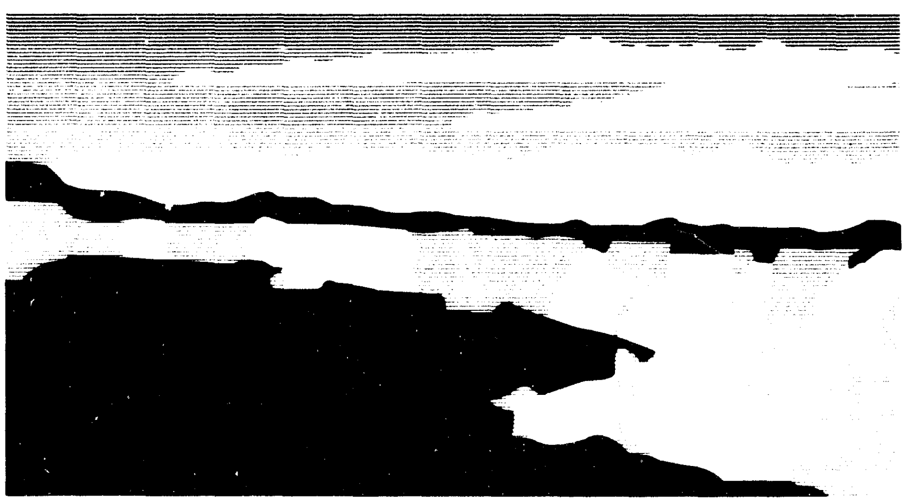

Los Alamos
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DISTRIBUTED ND-YAG LASER WELDING AND PROCESS CONTROL IN INERT GLOVE BOXES

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ABSTRACT

We have fabricated and assembled a fiber optic delivered Nd-YAG laser welding work station that consists of three glove boxes served by a single 1kw laser. Processing considerations related to the welding of special nuclear materials, toxic materials and complex part geometry are addressed within each work cell. We are proceeding with a development effort to integrate the equipment capabilities with remote sensing, process monitoring and control systems. These systems will provide real time data acquisition during welding, monitoring and verification of weld parameters, and CAD/CAM to CNC generated positioning paths. Computerized information storage , retrieval and network methods are used for weld process documentation and data analysis. A virtual control panel is being configured to integrate the monitoring and control operation of individual subsystems, such as laser and motion control into a single graphical interface. Development work on sensors to monitor laser beam characteristics and weld depth in real time with potential for adaptive control is in progress. System capabilities and results of these development efforts will be presented.

INTRODUCTION

Significant changes in the way the Department of Energy Weapons Laboratories and Production facilities conduct business are providing the driving forces necessary to re-engineer fabrication operations to accommodate changing requirements related to Environment , Safety, Health and Quality issues. Along with addressing these needs there exists a desire to down size the existing DOE weapons facilities yet retain fabrication and development capabilities. Flexibility and rapid configuration of fabricating environments is being enabled by advances made in integrating computer technologies into fabrication environments. Accommodation of these requirements have led to the development of a laser welding work cell which utilizes state of the art welding and computing technologies. This test cell will be used to evaluate and direct technologies for use in the DOE Complex 21 as well as serve a dual use for transfer of technology developed to foster industrial interactions.

System Hardware Configuration

The primary components which make up this laser welding test cell are a 1 kilo watt pulsed Nd:YAG oscillator amplifier industrial laser, three high purity argon glove boxes containing precision motion systems and an industrial computer workstation. Secondary systems include remote LED laser positioning senors, remote video viewing and recording, communications, monitoring and control subsystems and an eddy current weld inspection system. System integration is achieved through the use of serial communications, computer networking, computer based monitoring and control.

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System Software Configuration

Software developed in house and commercially available software provide for communications and data transfer between all primary and subsystem hardware. A TC/PIP computer network provides an electronic link to the process development environment. Three dimension CAD to CAM software is used to generate the computer numerical control code necessary to manipulate the three and five axis motion systems as well as control many of the laser functions. Post processors have been developed for each of the motions systems. The computer network connection also provides remote graphical terminal access to process related data stored on remote file servers. Electronic mail and file transfer protocols allow the transport of data of all formats to output devices and other information users. Virtual Control panels provide integration of subsystems control into a single user interface which allows the monitoring and control of the entire environment as a single system.

Motivational Issues For System Development

Environmental Concerns

The wastes generated within this environment are typically paper and paper-solvent mixed wastes. Potentially radiological mixed wastes may also be generated. Complete enclosure of the process within high purity controlled atmosphere glove boxes reduces handling, subsequent cleaning and much of the need for waste generation. Electronic means for document retrieval and handling also contribute to the reduction of the paper waste stream. Most maintenance of the laser welding system is performed outside the glove box environment leading to further reduction in waste generation.

Safety And Health

A fully enclosed laser beam either within the laser cavity, transport fiber or spectrally shielded glove box provides protection of the operator from direct exposure to the beam. Improved safety and reduced operator exposure is realized by isolating the joining process within the enclosed environment from the operator with respect to welding fumes , toxic materials, or radiological concerns. Reduced handling of parts contributes to reduced exposures to undesirable processing conditions.

Quality

Quality assurance and control benefits are realized through the access, acquisition, analysis and distribution of processing information. This system utilizes state of the art computer based electronic means for handling text, image and geometric data. Improved communications promote a more effective transport or access of information to the appropriate group of users.

Doe Complex 21

Consolidation of processing capability will be explored through the performance of GTA and EB welding, brazing and inspection operations into a single laser processing environment. Concurrent engineering tools for electronic design and process information handling tools will be utilized and evaluated.

Industrial Interactions

Process engineering, software development, and evaluations of actual processing case studies will become available to industry through participation of the Laboratory Staff in conferences.

Research in sensors and development of process sensing and control techniques and process modeling are areas of interest to the Lab which may offer opportunities for collaborative research with industry.

SYSTEM DEVELOPMENT AND CAPABILITIES

Weld Development

Pulse energy vs weld penetration studies demonstrated the ability to produce welds of penetrations up to 2.8 mm in stainless steel. The laser energy is directed to one of each of three glove boxes by the action of a pneumatically actuated fiber switching manifold.

Remote Monitoring

A non-contact LED laser height gauge is used to set the laser focal height and a remote 1/2" head video camera is used for alignment of the beam onto the weld joint as well as monitoring of the actual welding process. The video scene is dubbed with text describing system parameters such as position and laser energy during the weld operation through the use of a video text annotator. Remote monitoring of system status using serial communications and analog digital I/O is described below as a function of the virtual control panel.

CAD/CAM Control

Three dimensional CAD is used to establish part definition while CAM software is used to define the neutral tool path program file. Custom post processors have been developed to fully define motion system commands for each glove box hardware. Solid models of the parts and laser beam convergence cone have been modeled and used with the generated NC code to simulate the traverse of the beam along the weld joint while articulating all five axes of motion to assure correctness of the generated NC tool path. A full electronic link has been demonstrated for downloading of the tool path from the design computer to the motion system controller. This system allows rapid regeneration of a new path as a result of changes specified during weld development. Without this capability the operators would find themselves in the situation of attempting to teach/learn mode program point to point motion of the system enclosed in the glove box, an unworkable situation.

Virtual Control Panel

The various subsystems of this processing environment, when integrated, form a highly flexible system. Each primary subsystem is computer controlled but can be complex to setup, monitor and control. The primary and many of the secondary subsystem controllers have their own user interface and a serial communication port. An executive computer is used to communicate with these subsystems allowing a central location from which to set, monitor and control these devices. Multi-function I/O boards are used to monitor instrumentation and other devices without communication ports. Virtual control panels have been constructed for system setup, monitoring and control specific to each glove box. These process tailored panels, present to the user only the pertinent parameters for that particular operation thus simplify the amount of information presented to the user. For the laser welding system, system status, and trending of system operation is possible through access to pop up panels. Programming of the laser pulse shapes and monitoring of the actual shape of the pulse is possible through this system. Closed loop tuning of pulse heights is provided to obtain pulses set to actual joule values. This tuning accommodates changes in actual laser output over time for a given programmed pulse shape to changing system conditions such as flash lamp ageing. Control panels for the motion controllers used and monitoring of sensors and actuator states is also provided. Warning and fault status condition is also monitored and fed back into the systems control.

Electronic Information Interface

The windows based graphical computing environment supports remote graphical connections with other workstations and file servers as well as providing a full range of network communications and utility functions. Microsoft and X windows may be established to open multiple windows and tasks to display all file types such as color graphical images , CAD files, text, plot data etc. Links to file transfer, electronic mail and electronic data bases have been demonstrated. Links to Laboratory supported databases such as Material Safety Data Sheets, Standard Operating Procedures provide up to date access to these highly dynamic information sources. Processing work sheets, calibration and maintenance records can be remotely stored and access provided for all requiring immediate access to this information as in a safety or quality procedure audit.

A TOTAL SYSTEM APPROACH TOWARD WELDING

In addition to the establishment of process capability, documentation, and communication needs it is important to consider other aspects of the welding environment.

Integration Of Inspection And Diagnostics Into The Processing Environment

Eddy current weld testing is being integrated into the welding environment in an effort to eliminate handling, transport and to combine two operations into one set up. Ongoing research into process diagnostics such as using spectroscopy of the laser plume to determine melt volumes in laser spot welds of aluminum is being performed on similar systems in our laser research laboratory (Ref. 1). Other pulsed Nd:YAG laser welding research related to process characterization is ongoing (Ref. 2,3,4,5). This type of process characterization is necessary to determine the appropriate control variables and control methodologies for real time control systems and the reduction of welding defects such as weld cracking, the formation of porosity and voids.

Modeling And Simulation Of Welding And The Weld Processing Environment

Technical collaboration with keyhole weld modeling efforts (Ref. 6), and evaluation of such models (Ref. 7) is an ongoing effort which in the long term may provide alternative ways to predict weld morphology, microstructure and conditions difficult to quantify such as the stress state in narrow keyhole welds. Though not a direct part of the laser welding environment as currently configured, this research is important with respect to generation of a fundamental understanding of the process. Modeling activities utilizing the resources of the Advanced Computing Laboratory and the Materials Science Laboratory with respect to microstructural models and the modeling of solidification are ongoing at the Laboratory with new areas of collaboration actively being sought.

DISCUSSION OF SYSTEM AND SUBSYSTEM TESTING

The performance of fiber optic beam delivery has proven itself as not only a reliable and flexible means of delivering a laser beam for welding in a remote environment, but also an effective way to realize the safety benefits of a fully enclosed beam delivery system. Hermetically sealed glove box welding has shown itself to be an effective way to contain toxic or hazardous materials processing operations. Three dimensional CAD/CAM generation of numerical control codes has proved to be a necessary resource, particularly when the motion system is remotely mounted within a sealed environmental chamber. Minor changes to motion programs such as offsets to the welding joint are easily made, where teach/learns methods of programming would be nearly impossible. Miniature cameras, pointing and distance gauging lasers, are easily integrated into this environment, though their robust behavior during long duration fabrication efforts must be determined. The ability of 486 AT bus industrial workstation to perform with satisfactory speed in displaying and updating local and remote window environments on heterogeneous systems has been demonstrated. Sufficient resolution in the acquisition and display of graphics and digital microscopy/ photographic images has affirmed the current state of this technology for the evaluation of a reduced paper environment means of meeting the information needs within a radiological controlled area.

The computer monitoring and control of the laser and motion systems by the use of optical serials links has demonstrated the usefulness of integrating many independently controlled subsystems into a single user interface by the use of virtual control panels. The graphical feed back provided is useful in reducing the amount of information presented to the operator and providing a visual confirmation of system set up. Limitations to this form of communication and process control are primarily related the speed of the communications interfaces provided by the subsystems and the ability of subsystem computers and controllers to service interrupts.

In this particular development effort, the benefits realized by the combination of multiple joining operations into one welding environment had to be weighed against the complexity of the resulting processing environment. Highly trained technologists skilled in the use of advanced welding, computers, and computer based systems are presently being used for system operations. Just as complex are the rapidly changing requirements with respect to process information related to environment, waste management, safety, health and quality. Control of these issues with respect to the welding operations themselves constitute as much of a challenge as controlling the weld itself.

SUMMARY AND CONCLUSIONS

A laser welding system utilizing fiber optic delivery to 3 glove boxes has been configured. Multi-axis motion and laser control is realized through a 3D CAD/CAM distributed numerical control link. Remote sensors are integrated with primary subsystems by use of an executive computer and multiple communication links. A reduced paper environment is supported through the use of an Ethernet link and provides an electronic information environment to support environmental, safety, health and quality programs.

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