ROBOTIC ARM HUMAN-MACHINE INTERFACE FOR LASER SHOCK PEENING APPLICATIONS

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The HiLASE Centre is equipped with a Laser Shock Peening station (LSP). LSP is a surface enhancing technique and it is used to prolong the fatigue life of metallic components. Part of the station is a FANUC M-20iA/20M 6-axis industrial robotic arm equipped with an R-30iB controller. The robotic arm is used to handle the LSP samples In order to facilitate the utilisation of the LSP station at the HiLASE centre for untrained operators, a human-machine interface (HMI) for the station's industrial robotic arm is being developed. This project aims to determine what type of HMI is the most suitable for the given application and to implement this solution.

1 INTRODUCTION

The Laser Shock Peening (LSP) station at HiLASE is equipped with a 6-axis industrial robotic arm. Learning to program an industrial robotic arm using a teach pendant has a steep learning curve and requires special training. This is mainly because different robotic arm vendors use different Operating Systems (OS) and different programming languages for their respective teach pendants. It is ineffective and time consuming to provide every employee with the same level of training required to program a robot application. In consequence, there is a need to develop a unifying HMI for the LSP station, which allows the operator to control the process and change the process parameters via a Graphical User Interface (GUI).

2 LASER SHOCK PEENING

LSP treatment induces residual stresses beneath the treated surface of metallic materials. The residual stresses are produced by a high magnitude shock wave induced by a high-energy laser pulse. The advantage of LSP is that the laser pulse can be adjusted and controlled in real time. A computer-controlled system can measure the energy per pulse and record it for each LSP process on the component [Mannava 1998].

2.1 Laser Shock Peening Process

The configuration of an LSP process on a metallic component is as follows (see Fig. 1). An intense pulsed laser shock beam is fired onto a metal surface for a very short amount of time (10-100 ns). The heated zone is vaporized and transformed to plasma by ionization due to high temperatures (over 10 000 °C). The plasma is under high pressure, which propagates through the material via shock waves. Two modes of LSP exist – the direct ablation mode and the confined ablation mode. The direct ablation mode refers to interaction of plasma with a metal without coating and confinement. Plasma pressure of tenths of a GPa is achieved using direct ablation mode [Sano 1997]. Higher pressures of 5-10 GPa can be obtained using the confined mode. In the confined mode, the metal surface is usually coated with an opaque material such as black paint or aluminium foil and confined by a material transparent to the laser radiation such as distilled water or borosilicate glass. A stronger pressure pulse results in a higher magnitude of compressive residual stress to a deeper depth [Fairland 1974].
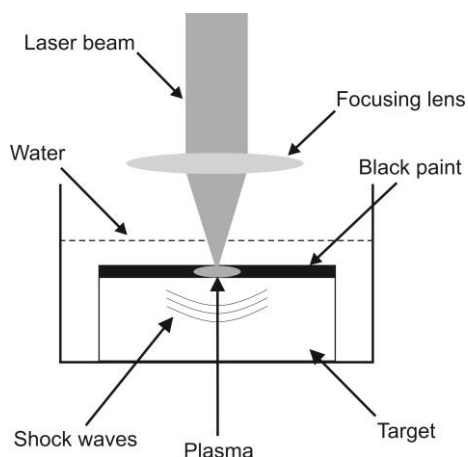

Figure 1. Schematic configuration of laser shock peening

2.2 Laser Shock Peening Strategy

During the peening process, a pattern is created made of individual laser pulses. Generally, multiple sequences of the pattern that are gradually shifted across the sample are used to create a layer (see Fig. 2). The pattern shifting ensures more homogeneous residual stress distribution. The disadvantage of this peening strategy is that the protective coating needs to be replaced in between sequences [Kaufman 2018].
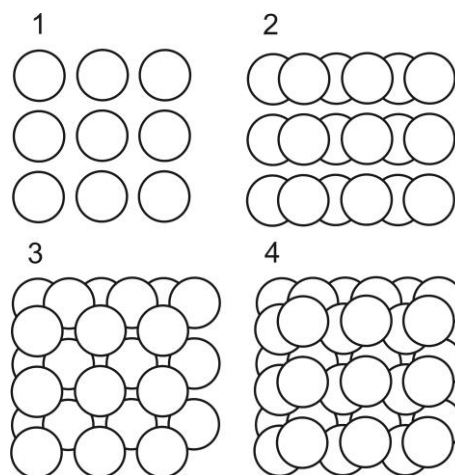

Figure 2. Laser shock peening strategy – one layer consisting of four sequences

3 LASER SHOCK PEENING STATION

The LSP station uses the Bivoj laser system, located in the clean L2 laboratory on the ground floor of the HiLASE Centre. A Laser

Beam Distribution System (LBDS) transports the beam to experimental laboratories on the 1st floor. The Bivoj laser system is a Diode Pumped Solid State Laser (DPSSL) based on Yb-doped gain media with a laser wavelength of 1030 nm capable of delivering pulses of energy up to 8 J at 10 Hz repetition rate. The beam shape at output of the Bivoj laser is a square flat top pulse. The two main parts of the Bivoj laser are the front-end and the 10 J amplifier.

3.1 Bivoj front-end

The front end starts with a fiber-based section, which consists of a fiber oscillator, fiber amplifier and temporal pulse shaper with 125 ps resolution. The output of the fiber front-end is fed to the first booster amplifier which is regenerative and increases the energy to 3 mJ and reduces repetition rate to 10 Hz. The second booster amplifier works in multi-pass regime and increases the pulse energy to approximately 30 mJ. Repetition rate can be chosen between 1 Hz and 10 Hz. The beam shape at the front-end output is 8x8 mm^2 square flat top.

3.2 Bivoj 10 J amplifier

The 10 J amplifier is the first-stage main amplifier based on cryogenically cooled multi-slab technology. The principal component of the amplifier is the amplifier head, where the gain media are stored and cooled by gaseous helium to a temperature of about 150 K. The laser beam from the front-end is enlarged to 21x21 mm^2 and sent to the 10 J amplifier, where increases its pulse energy from approximately 30 mJ to approximately 6 J at 10 Hz [Saumyabrata 2015].

3.3 LSP station

The layout of the LSP station is as follows (see Fig. 3). The laser beam enters the LSP station through the LSP output node and continues to the optical table, where it is redirected and focused on the target. The target itself is mounted on the robotic arm. The position of laser beam is fixed, so the robotic arm needs to be moved to direct the position of the laser spot on the sample [Kaufman 2018].
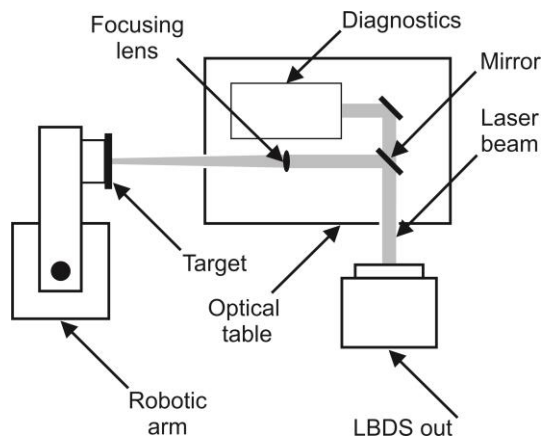

Figure 3. Schematic layout of LSP station

4 PROGRAMMING IN LABVIEW

4.1 HMI requirements

Based on the experience with operating the LSP station, the following function requirements were considered:

- The HMI must provide a way to select the peening parameters, namely the number and size of patches, the robot motion speed and sequence shift.

- The program must display the robot controller status, the program status and the current robot position and orientation.

- The program should inform the user whether the laser is running and the user should be able to remotely turn off the laser

- The program must handle error recovery in the case of a safety violation.

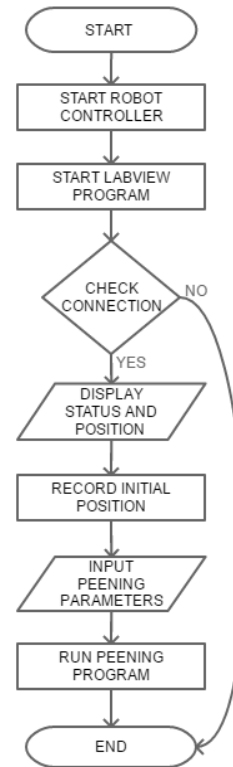A simple conceptual design was also proposed in the design phase of the HMI development (see Fig. 4).

Figure 4. Conceptual design of HMI

Currently four main types of robot HMI are used in industrial applications. The following chapter discusses, in short, their advantages and disadvantages for HMI creation.

- Hardware buttons – These buttons are usually connected to the Programmable Logic Controller (PLC) or Emergency stop board of the robotic arm controller. This solution is very robust. However, it is not very extensible.

- Teach Pendant – A teach pendant is usually supplied with the robotic arm. They run the robot controller OS and allow the developer to create their custom GUI. The main drawback of teach pendants is that learning creating a custom GUI on a teach pendant has a steep learning curve.

- HMI panel – These panels are rugged touch panels that are shipped with designer software to create custom GUIs. Their main disadvantage is their higher price.

- Computer GUI – This option is the most flexible and relatively low-cost. On the other hand, it is not so rugged as an HMI panel or teach pendant.

FANUC Robotics does not offer a programming interface that enables external superior control systems to control the robotic arm motion. For example, the company KUKA® offers such a solution called KUKA.PLC mxAutomation®. KUKA.PLC mxAutomation supports a wide range of PLCs from different manufacturers and is integrated in their respective

development environment, so the program developer does not need to learn KUKA's proprietary teach pendant language. Such a solution, provided it would be offered by FANUC Robotics, would be a viable alternative to the LabVIEW solution presented in this paper.

4.2 LabVIEW development environment

LabVIEW® (Laboratory Virtual Instrument Engineering Workbench) is the development environment used in this project. LabVIEW uses graphical notation to create applications instead of lines of text. LabVIEW programs are called Virtual Instruments (VIs). LabVIEW is used for data acquisition, signal processing and hardware control. A LabVIEW program consists of the front panel window and the block diagram window. The front panel window contains controls and indicators (i.e. inputs and outputs). The block diagram window contains terminals corresponding to front panel controls and indicators, as well as constants, functions, structures and wires that connect data from one object to another [Bress 2013]. The LabVIEW 2015 64-bit Full Development System is used.

The Digimetrix® Fanuc Robotics Library add-on is used to simplify the application development process. The solution incorporating the Digimetrix library is unique compared to standard procedures of robot control from superior systems (PC, PLC, CNC) used in industrial automation because it enables the developer to access all of LabVIEW's capabilities. In this way, advanced measurement and machine control can be integrated using a single LabVIEW application and the developer can tailor the program to his needs. Furthermore, the program is mostly hardware independent, so the code can be reused.

4.3 Digimetrix Fanuc Robotics library

The Digimetrix Library uses the Fanuc User Socket Messaging Communication Option. Socket messaging enables data exchange between networked robots and a remote computer via TCP/IP Sockets. The Transmission Control Protocol (TCP) is intended for use as a highly reliable, host-to-host protocol between hosts in packet-switched computer communications networks. It fits into a layered protocol architecture just above a basic Internet Protocol (IP). The IP provides a way for TCP to send and receive variable-length segments of information enclosed in Internet datagram envelopes. The Fanuc Robotics Library enables the controller to communicate with external or host devices across an Ethernet network. The PC with LabVIEW acts as a client and the robot controller as a server (see Fig. 5).

The advantage of the Digimetrix library is that it offers an extensive amount of functions. These functions allow to control almost every aspect of the robotic arm. It is also deeply integrated into the LabVIEW environment. The disadvantage of this library is that the developer has to be familiar with LabVIEW at least on a basic level. Another disadvantage of the library is that TCP/IP itself does not support real-time operation.
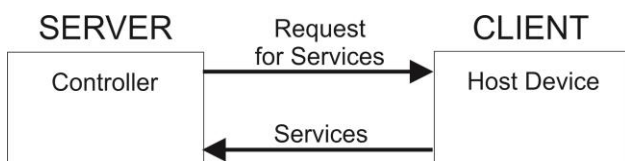

Figure 5. Client-server configuration of host PC and robot controller

5 LABVIEW PROGRAM ELEMENTS

The LabVIEW program itself is split into several segments, each having a different functionality.

5.1 Ethernet communication and execution state of VI

The Ethernet communication establishes a connection with the FANUC controller using an Ethernet interface. The user inputs the IP address of the controller and the port number of the application. A control LED serves as an indicator if the communication was established successfully. The execution state of the VI indicates if the VI is bad, idle or running.

5.2 Controller status and current position

The controller status window unites the various settings of the robot controller (see Fig. 6). The current position window obtains the current robot position in Cartesian or joint angle coordinates. The current position function cannot guarantee high accuracy of returning the arm current position while the robot is moving.

Figure 6. Front panel of Ethernet communication, controller status and execution state

5.3 Recording position and program registers

The user needs to record the initial position on the sample before starting the peening program. The record button reads the current position and sets and displays a position register. This position register is then assigned to a point in the TP program loaded on the robot controller. The program registers function in a similar way. The values of the registers are entered by the user and then loaded onto the robot controller as integer registers. The TP program on the robot controller then loads these integer registers. The program registers set parameters of the peening process like spot size, patch size and number of patches. The robotic arm moves linearly with constant speed between two discrete points when the laser is firing. This ensures that the pattern created on the surface of the material is uniform.

5.4 Running program

After loading the program registers, the user can run the selected program on the robot controller. The interface informs the user about the program status, the current line of the program and the status of the laser, sequence number and water and air supply. The program keeps track of the sequence number and notifies of the need to change the sacrificial layer (i.e. vinyl or aluminium tape).

5.5 Handling safety violations

The robot movement can be started directly from the HMI, but only if AUTO mode is enabled. AUTO mode requires the safety equipment to be connected to the emergency stop board of the robot controller. The Digimetrix library is capable of handling safety violations. The status of the program error state and the controller fault state can be reset. Some errors (position unreachable, singularity, pressed Emergency stop) cannot be reset programmatically and the reason for the error has to be removed manually. Nevertheless, the Digimetrix library can restart itself automatically after the cause for the unresetable error is removed and then continue operation. The user can also remotely shut down the laser.

5.6 Laser shock peening of arbitrary shapes

A LabVIEW program was developed for peening arbitrary flat shapes. The user chooses the following peening parameters: the spot size, linear speed and the geometry of the peened

area. The geometry is saved in a Boolean matrix (see Fig. 7) where every point represents one laser shot. The user chooses the area to be peened by clicking on the respective points of the matrix.
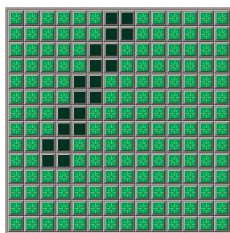

Figure 7. Boolean matrix for drawing arbitrary shapes. The user can create their own 2-D shapes. This is particularly useful for testing crack propagation and for small scale production

The point matrix dimension is determined and the matrix is split into individual rows. A 1-D linear array search scans the row. The row does not have to be ordered, because the search is linear. If a match (LED state on Boolean matrix is ON) is found, the position of this point is computed. The program instructs the robotic arm to move to the last position where a match was found. The program starts the water and air supply and waits for a fixed period of time for the water flow to stabilize. The program then awaits the arrival of the laser synchronization signal via a digital input of the robot controller's PLC. Firing the laser is achieved by sending a digital pulse to a fast shutter via a digital output of the controller's PLC (see Fig. 8). The fast shutter is located in the L2 laboratory at the beginning of the LBDS. The shutter's rise and fall times are around 30 ms, so it is possible to pick individual laser pulses. The program moves to the next row after reaching the end of the current row and repeats the algorithm.
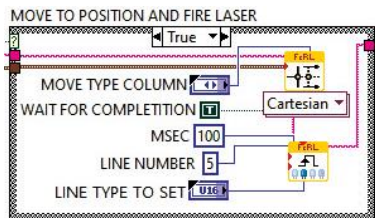

Figure 8. Block diagram of laser firing procedure

6   CONCLUSIONS AND ONGOING WORK

The LabVIEW interface was tested under simulated conditions to verify adequate responses from the robotic arm. Since this was achieved, users can now input program parameters directly into the interface. The initial results show that an untrained operator is able to operate the LSP station independently. The use of a HMI also shortens the production chain and no additional programming is required. Thus greater flexibility of the production process is guaranteed.

The laser shock peening of arbitrary flat shapes is a much needed functionality for the given application and would otherwise take much more time and resources to implement if

standard procedures of robot control from superior systems (PLC, CNC) would be used instead.

Plans include running the LabVIEW program more fluidly out of simulation as well as implementing the program to connect to a power meter. The user will also be able to choose between different strategies of overlap of individual pulses in the future. The program can be applied to only to flat surfaces so far. In the case of non-flat surfaces, the Boolean matrix would need to be projected onto the non-flat surface and collision avoidance between the laser and the part itself would need to be implemented.

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