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An Industrial Product-Service System approach for Laser Process Quality Control

D. Mourtzis [a]*, N. Boli[a], K.Alexopoulos[a], P.Pittaro[b], A.Terreno[b]

[a]*Laboratory for Manufacturing Systems and Automation, Department of Mechanical Engineering and Aeronautics, University of Patras, 26500, Rio Patras,*
[b]*PRIMA INDUSTRIE S.p.A., Via Antonelli 32, 10097 Collegno (TO), Italy*

* Corresponding author. Tel.: +30-261-0 99-7262; fax: +30-261-0 99-7744. E-mail address: mourtzis@lms.mech.upatras.gr

Abstract

A framework for a two-way interaction between laser machine operator and a laser machine supplier in the direction of Laser Process Quality Control (LPQC) is proposed. An optical system is used to verify the beam alignment referred to the nozzle hole and the wear state of the nozzle in terms of process quality. The proposed framework provides the basis to laser suppliers for shifting their business model to Servitization. A case study is presented with the provided Industrial Product-Service System to consist of a laser-cutting machine and a service entitled LPQC.

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Keywords: Quality Control; Laser Process; Industrial Product-Service Systems (IPSS)

1. Introduction

The manufacturing environment is now more complex and dynamic than ever having passed in the era of Industry 4.0 [1]. Moreover, customer demand and globalization are the trends positioned at the first place of the manufacturers' agenda today [2]. Considering those facts, industries, in order to improve their competitiveness and sustainability, are shifting their business models providing Industrial Product-Service-Systems (IPSS), increasing in such a way the added value of their products [3].

Following the aforementioned, with an aim to manage uncertainty in the new manufacturing era, this work proposes a framework for a two-way interaction between laser machine operator and laser machine supplier in the direction of Laser Process Quality Control (LPQC). This collaborative framework is for the support of process-based product service systems for equipment manufacturers in order to maximize the impact in the European industry. The proposed framework provides the basis to laser machine suppliers shifting their business model to Servitization.

In particular, this service's purpose is the automatic verification of the right setup of the most critical settings related to laser cutting process. This service targets to help the laser machine operator to check and set the right parameters for the optimal laser process. In addition, IPSS provider will use this service to have an objective feedback from the system settings, in order to investigate the real operating conditions of their laser machines. Thus, this service targets to improve both the design and use phase of a laser IPSS.

The remaining of the paper is structured as follows: the second section comprises a state of the art at the main aspects of this work. Section three presents the proposed methodology and the proposed system architecture. In section four, the experimental setup and the application of the proposed methodology are going to be presented with the industry's perspective on that. The presented case study consists of a laser-cutting machine and a service entitled Laser Process Quality Control. This paper concludes with a summary and the intentions for future work.

2. State of the art

Over the last years, it has been observed an improvement of the information systems and an increase of the need to fulfill customers' needs [4]. In order to survive and be competitive,

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manufacturing companies offer services combined with products, so they create Industrial Product-Service Systems (IPSS) [5]. An IPSS is an integrated product and service offering, that delivers values in industrial applications and includes the dynamic adoption of changing customer demands and provider abilities. Industrial Product-Service Systems are individualized, customer-oriented configurations of products and services, which affect each other due to their integrated development and provision [3]. This integrated understanding leads to new, customer-adjusted solutions. The adoption of the IPSS from the industries allowed the creation of business models with main purpose the increase of their competitiveness and their profit [6], [7]. The IPSS are classified into three main categories: product-oriented, use-oriented and result-oriented [8]. In summary, the IPSS business demands a paradigm shift towards selling functionality instead of selling products.

The shift of the manufactures from products to IPSS is called Servitization and it was first discussed by Vandermerwe and Rada in the late 80s [4]. The continuous progress of digital technologies especially the last decade gives a solution to the problem and enables firms to improve service quality, reduce operational costs and change the way they compete [9]. This is called digitalization or digital Servitization [10]. Digitization of all the systems is the key of smart manufacturing with other key characteristics to be the Context awareness, Adaptability, Flexibility and Networkability [11].

Industry 4.0 leads to physical systems transformation to cyber-physical systems (CPS). The reduced cost of computing power enables mobile device applications which support wireless access to data and may host user- friendly user interfaces that provide production line technicians with machine- related information. Sensors mounted on industrial machinery allow constant monitoring of its state while using this data to predict future tasks that may be needed [12].

By focusing on laser cutting processes, it becomes apparent that laser cutting is the most cost-effective cutting technology that produces clean, smooth edges, extreme accuracy, and repeatability [13]. Generally, laser cutting is best suited for thin material such as carbon or stainless steel and thin aluminium. It is important to introduce the main laser cutting process parameters, which are found to be the power, pulsed/CW, the gas supply, the cutting speed, the nozzle diameter and nozzle distance, the focus position, the Metal thickness and the Laser spot size. Laser process parameters have to be adjusted carefully in order to avoid influencing on part quality [14], [15]. In the Fig. 1 below some indicative Laser Cutting Process Input and Output, parameters are presented. The Input parameters are controlled parameters. They are controlled and adjusted by the CNC controller. In addition, other very important parameters for a good quality are the Laser Head setting parameters (focal position, beam alignment, nozzle tip, and lens integrity). These settings are executed substantially by manual operation and the evaluation of correct settings is operator-subjective. These critical factors are an obstacle to keep a constant quality as also an insuperable problem for an unmanned production. The automatic check of these settings allows controlling and adjusting the right conditions for better process quality, saving time, energy and material.

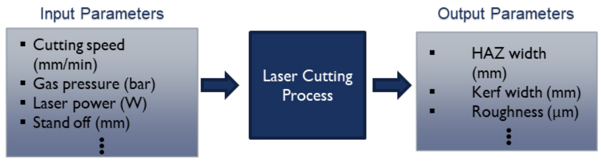

Fig. 1. Laser Cutting Process Input and Output parameters

Manufacturing Key Performance Indicators (KPIs) monitoring is very important since through gathering and processing those measurements, the process quality can be evaluated [16]. Different approaches have been introduced for Laser Process Quality Control focusing on Measurement of evenness of the working table, pressure test of the working table or control of power supply voltage and electrical safety. Additionally, process parameters optimization using systematic design of experiment (DOE) to obtain burr free laser cuts with minimal cut edge surface roughness is proposed by [17].

Realizing the need for Laser Cutting - Remote Process Quality Control, a Product-Service System for Laser Cutting Process Quality Control is proposed in this work.

3. Laser Process Quality Control: Industrial Product-Service System Architecture

3.1. Industrial Product-Service System

The proposed approach aims to the composition of an IPSS solution allowing a two-way interaction between IPSS customer and provider. IPSS is the prominent business model for sustainability, introducing the strategy of combining the product with services in one bundle. This approach will benefit both provider and customer leading to a win-win situation.

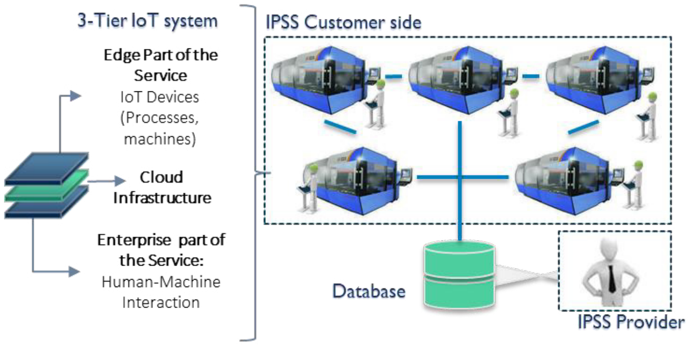

Fig. 2. Lase Process Quality Control: Industrial Product-Service System approach

The proposed approach is going to be offered as a product-oriented product service system, which aims to increase the competitiveness, productivity, and efficiency of the interaction between the IPSS Provider and Customer.

Additionally, a main advantage of the proposed product-oriented IPSS approach is that manufacturers are not required to change their business models to a high degree in order to adopt this solution.

This approach utilizes a three-tier Internet of Things (IoT) system as it is presented in Fig. 2. In particular, in the 'edge part of the service' IoT devices (optical systems) are installed in order to monitor the process and machine conditions. The data are collected locally and transmitted in a cloud database accessible from both the IPSS Customer and the IPSS Provider.

3.2. System Architecture

The proposed system architecture is depicted in Fig. 3 below. In particular, a six steps methodology is proposed. The scope is to provide quality control through the use of an integrated machine vision system that checks laser head setting quality.

- Step 1: Collection of images in the IPSS Customer side through a vision system.
- Step 2: Data uploading to the cloud.
- Step 3: Data processing and interpretation based on sort of tolerance range related to the quality certification standards (measure of precision accepted by Laser Provider). The measured quality should be compared with the quality certification standards. Data and KPIs repositories are going to be utilized. This will help to understand if the customer has the right setups.
- Step 4: Notification regarding Process Quality. If the measured value is not compliant with the tolerance a notification will be sent to the IPSS user. Simultaneously, collection and storage of the verification data on the laser machine system side is going to take place.
- Step 5: Nozzle replacement or setup recommendations are going to be given to the IPSS user.
- Step 6: Management and verification data are stored in the cloud in order to be reused by the IPSS provider in the future improving in that way the design phase.

In the following figure, the most crucial Laser Process quality indicators related to the head setting parameters are presented. The appropriate model and good state of the nozzle tip, the correct setting of the focal length, the correct lens alignment and the state of the lens are fundamental settings for a good cutting process. The beam alignment and the Nozzle Tip integrity are important for the process because the cutting is performed in all directions it should have the same condition in term of interaction of laser beam-gas flow-material surface. If deviations exist and the symmetry is wrong, gas flow around the beam and the laser beam referred to the metal sheet are affected and thus the system cannot perform the process with the desired quality.

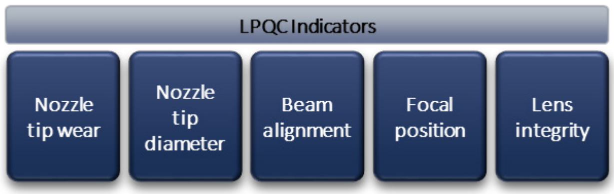

Fig. 4. Laser Process Quality Indicators

In particular, the Nozzle Tip status could have the following states:

- Good (green indicator) – State necessary for a high accuracy, strict tolerance cutting
- Acceptable imperfection (Yellow indicator) - State acceptable for a high tolerance cutting but replacement is going imminent
- Bad (red indicator) – Nozzle tip needs to be replaced

The optical verification is also for the nozzle tip correct diameter selection, which is determined by the metal sheet processing type. The verification of the right Nozzle tip diameter is a very fast operation due to the verification of the real tip diameter in a defined discrete range of possible diameters.

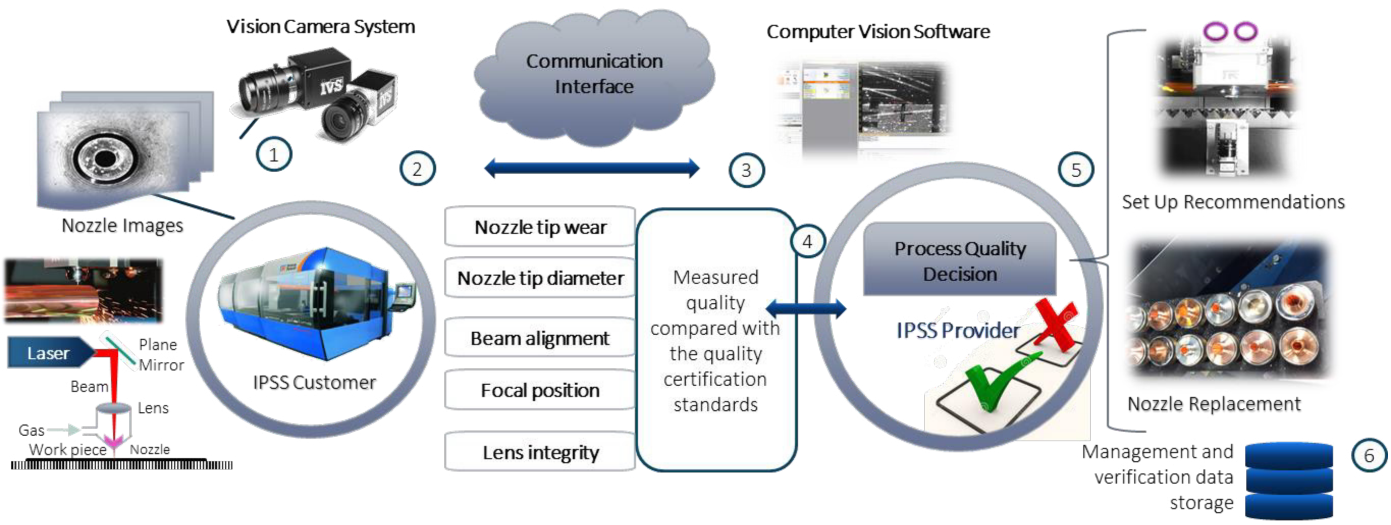

Fig. 3. Methodology Workflow

This check will guaranty that the cutting process will start with the required nozzle tip and a possible mistake in the nozzle tip storage will be adjusted. The focal position depends on the lens and is identified using a dedicated procedure that utilizes a particular beam emission and focal axis movement. In that way the correct focal position is identified and automatically is corrected by sending a command to the CNC controller to update and memorize the right focal position

For Beam alignment, the tool will show the movement needed to adjust the position. The operator currently performs this manually. About the lens integrity check, the tool will be able to analyse some transmission characteristics of the lens to understand the grade of integrity of the lens to alert the system if a warning or replacement is needed. While the check is performed automatically, a manual adjustment is performed then.

Nozzle tip wear and beam alignment are among the most important parameters taken under consideration in the proposed Laser Process Quality Control provided service. Thus, the verification of those two is presented. The Nozzle tip analysis is performed checking the circularity of the hole and the existing deviations as it is presented in Fig. 5.

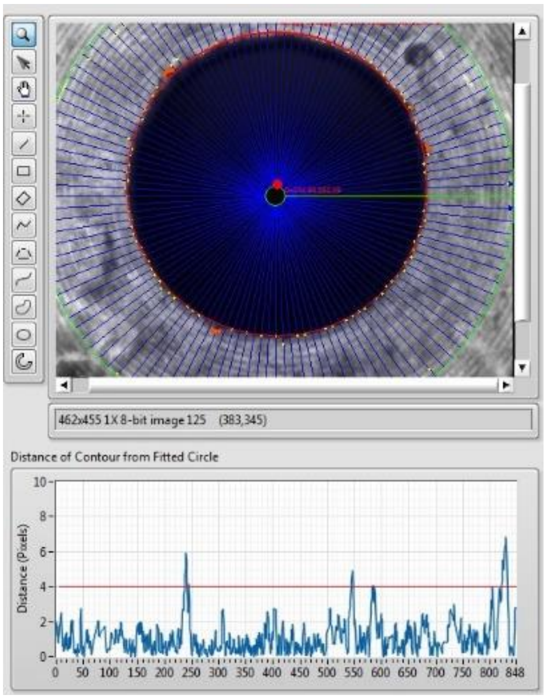

Fig. 5. Nozzle Tip wear analysis

In particular, by receiving and processing images of the nozzle tip, the circularity of the hole is evaluated. As it is presented in Fig. 6, the deviations of the reference cycle of the nozzle tip are plotted and presented compared to a threshold in order to verify the nozzle tip wear.

To verify the beam alignment the system will measure the position of the beam referred to the tip hole. The beam alignment is performed by moving the lens. The procedure to check the laser beam alignment is called Verification Precision Optic. The check of the focal position and beam alignment will be made with a precision better than 0.1 mm and nozzle tip circularity better than 0.05 mm. It is assumed that the laser process is correct (from the laser head setting point of view) when these conditions have been achieved.

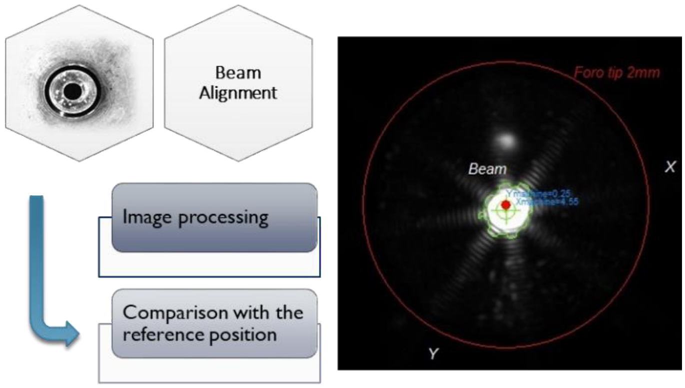

Fig. 6. Beam position referred to the tip hole

Following that the evaluation of the laser process quality in terms of settings, is going to be achieved and the relative instructions are going to be given in order to make the appropriate corrections.

4. Case Study

The company of the case study is a world-class laser machine manufacturer with more than 2000 employees worldwide and Manufacturing facilities in Italy, Finland, USA and China. The proposed IPSS is going to be provided as an application using mobile devices mobile app or smart watch preferable. The tool will also have a standalone operability even if the network connection is not active. That means, more than to send data to the cloud, a local operation would be able to be performed on the system, in order to adjust the head settings or to have the status of them.

The Laser Machine settings are provided by the laser machine operator based on his experience. There are also methodologies and references to guide the operator to evaluate and adjust these settings but the human factor involvement is critical, in order to reach the desired result. The introduction of Laser System Machine in a massive production factory increases the request for an easy and reliable check of the laser process settings. Offering a specific and automatic service to objectify the setting of the right conditions for a good technological process, will guarantee the appropriate productivity of the Laser System. This means a great saving of time and cost for the end customer.

The system for this service is based on a specific camera vision system mounted in a defined and well-fixed position of the Laser System Machine related to the laser head. LabView SDK is used for data acquisition, instrument control, and industrial automation on the operating system. The camera is connected to a stand-alone PC with an application synchronized also with the CNC controller to execute the service in automatic mode. Camera positioning is depicted in Fig. 7.

Specific light and shielded connections are provided to allow a reliable operation inside a heavy industrial environment. To work in an industrial environment and to have the best condition for the camera vision dedicated lights to illuminate the laser head should be used.

Fig. 7. Camera positioning

The camera connection must be noise-free to avoid image distortion. The camera selected has a resolution of 5M, 20 frames/sec, b/w, digital connection via Ethernet. The camera vision will be positioned under the head, looking the Nozzle Tip and the laser beam inside and a dedicate support holds the camera. The camera system will be positioned out of the working area where the system can be moved only in a special procedure (no cutting) only to verify the LPQC parameters. The measurement is performed offline and the frequency to execute the check takes place before a new program start. Then a program can work for some minutes or for some hours.

In one hand, the laser machine operator may use this service in order to have access to the functional conditions of their machines and to continuous tracking possible issues in order to improve their design and provide sustainable solutions to their customers. The company's GUI is presented in Fig. 8 below.

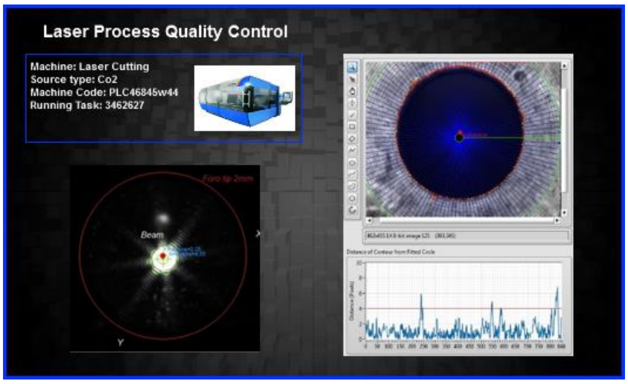

Fig. 8 Laser Process Quality Control IPSS Company view

In particular, on the left side of the GUI basic information regarding the specific machine is presented together with the beam alignment state referred to the predefined position. On the right side of the figure, the nozzle tip wear is evaluated in order to send a suggestion to the customers.

Simultaneously, in the following Fig. 9 the IPSS customer interface is presented. The first step is the user to select a specific machine from a list of all machines. By navigating to the specific laser cutting machine view he will be able to have a look at machine's basic information together with the current process parameters and the task performed. Additionally, the customer will receive five alarms through this screen. The first one is related to the Nozzle Tip Diameter in case the not appropriate one as it came from the CAM system has been selected. The second one regards the Nozzle tip status, which as it was mentioned in the previous section, could have three different states based on its wear (Good, Acceptable and Bad). Considering that the system has an automatic tip changer, after checking the Nozzle tip with a "Bad" status the system will change automatically the tip. The third one is an alarm regarding that an automatic focal position adjustment is taking place and the third one will be a beam alignment guidance. Focal adjustment is achieved in an automatic way. Accordingly, for beam alignment, there is an indication for the operator. Finally, an alarm regarding the lens integrity is going to be provided. Then a new test checks if the manual corrections have been done correctly.

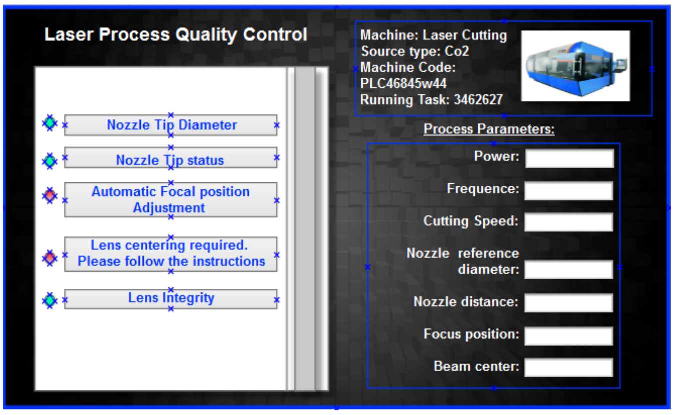

Fig. 9 Laser Process Quality Control IPSS Customer view

Except this GUI, the IPSS customer can receive independently three tools referred to Nozzle tip Store, Focal adjustment tool, and beam alignment tool. Here a page to set the focal position, a page to show the beam alignment, which could be checked in a semi-automatic way executing a cutting program and the page to manage the nozzle tip store, are presented. Subsequently, in Fig. 10 the CNC control interface for the laser system is presented. The focal position and beam alignment will be checked with a precision better than 0.1 mm and nozzle tip circularity better than 0.05 mm.

5. Conclusions

This work proposes a process-based product service system for equipment manufacturers. This approach can be applied to other, no laser-based processes giving the opportunity in one hand to the IPSS providers to improve their design from the received feedback and on the other hand to the IPSS Customers to optimize the use of the equipment by receiving appropriate use instructions. More than that remote collection and data record can offer to the IPSS provider the possibility to sale additional services about the analysis of data to assure a better use of the system (cost optimization and better quality).

Intentions for future work are concentrated firstly to the creation of a dedicated optical system to verify the beam

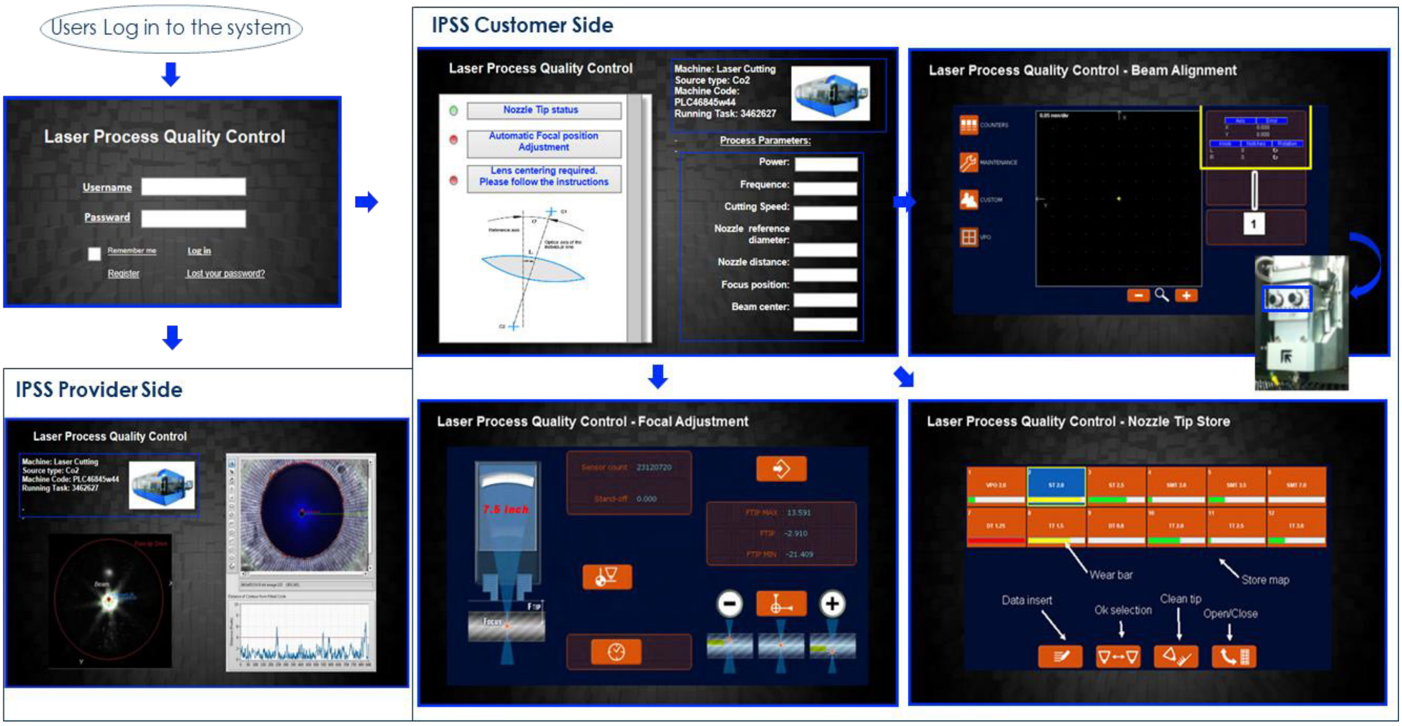

Fig. 10 Laser Process Quality

alignment referred to the Tip hole and also the wear state of the Tip for process quality control. Secondly to the application of Data analysis on the collected data improving in such a way the design of the machines.

In addition, the process parameters relationship with LPQC by the definition of some thresholds is going to be modelled. Finally, this service is going to be provided as an Android application for smartphones and tablets.

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