

Creation of a control system for plasma delivery to increase determinism and robustness while processing using an ICP torch

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Abstract

The Cranfield University Precision Engineering Institute team has created a unique plasma figuring capability to correct large optical surfaces at atmospheric pressure. In the context of ever-increasing dimensions of optical components, there is a need for improving the robustness and securing the performance of our Plasma Delivery System (PDS). The current PDS is based on an inductive output L-type RF circuit, Inductively Coupled Plasma (ICP) torch and computer numerically controlled (CNC) motion system. The combination of optical component surface areas and the nature of the sub-aperture plasma tool lead to significant processing duration. This atmospheric pressure processing environment is more cost-effective than vacuum chamber based ones which are often used by competitors. However, it requires deep awareness and a fine understanding of technologies used. Based on the knowledge acquired for the past eight years, we have created a smart control system for our unique PDS that equips a machine called Helios1200. This novel control system aims at securing the process determinism and assisting the machine operator by tuning some key electrical components of the RF network and monitoring some processing parameters. Furthermore, specific assistance is provided during the different phases of the plasma processing. This paper describes the main design aspects.

Inductively Coupled Plasma, RF generator, RF network

1. Plasma Figuring Technology

This work supports the development of the Plasma Figuring (PF) technology [1]. PF provides a unique rapid surface figuring capability for large optics. PF benefits from bespoke plasma tool and tool path algorithm. PF has been shown suitable to process silicon based materials.

At Cranfield University, there are two plasma figuring machines. They are called RAP300 [2] and Helios1200 [3] (Fig. 1). These machines combine plasma technology operating at atmospheric pressure and computer numerically controlled (CNC) motion systems. However the radio frequency (RF) plasma systems are different. RAP300 is equipped with a matching network RF network, unlike Helios1200 that is equipped with a fixed match RF network [1].



Figure 1. RAP300 (left) and Helios1200 (right).

In each machine, an RF inductively coupled plasma (ICP) torch is used to atomize the reactive gas and create free radicals [1]. The combined torch, RF network, and signal generator will be named Plasma Delivery System (PDS) in this paper. The

electrical designs of these two PDS are based on inductive output L-type RF circuit. In Helios1200, a fixed match electrical design was chosen because this design enables to reduce the weight of the plasma torch assembly. Thus, the axis of the CNC machine tool that drives the torch has better dynamic performances and consequently higher capability to correct complex surfaces. Here below the torch assembly and the electrical circuit (RF network) are displayed [5].

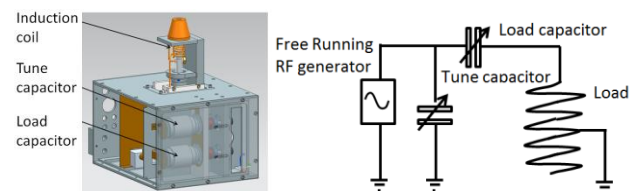


Figure 2. Torch assembly (left), inductive output L-type RF circuit (right).

2. Research motivation

The aim of this project is to secure hundreds of processing hours for PF of metre scale surfaces. This aim will be reached by designing a novel control system to monitor and assist the PDS of Helios1200. Hereafter are detailed features that the control system does ensure.

2.1. Expected capability of the control system

The capability of the novel system is to control the impedances of the load of the PDS and monitor the reflected power of the RF signal generator.

The first capability will be secured through the modification of the torch assembly through the motorization of capacitors. Thus, a certain degree of automation will be implemented in the PDS. The second capability will be secured by a microcontroller, microactuators, and sensors. This capability will enable to gather in-flight process information for diagnostic purposes.

Indeed, authors have identified the important features that are needed for the entire range of operations. Thus, the novel features of the control system address plasma ignition, regular plasma delivery, and critical circumstances. These three phases are experienced during regular operations. Details and benefits of each phase are provided hereafter.

Plasma ignition phase is characterised by moderate RF signal power $\sim 300\text{W}$ and tuning of the capacitors. Regular plasma delivery phase $\sim 1.2\text{kW}$ is characterised by monitoring of various parameters such as reflected power, coolant temperature and gas temperature. Critical circumstance is a phase where unexpected events may occur. Shutting down of the PDS will be executed to preserve its integrity.

3. Novel approach for RF circuit design

3.1. Way to overcome the need for matching network

The matching network enables to tune the impedance of the loads. This load is typically made by coil, load capacitor, tune capacitor, and transmission line. The matching network maintains the plasma in stable condition. Thus, temperature increase of the electrical components, environmental perturbations, and process parameter variations cannot disturb critically the plasma created by the RF network. From a technical viewpoint, capacitors are motorized to tune the impedance of the load. However matching network systems are expensive, heavy and have moderate capability to quickly tune the load. This underscores the need for a new load tuning system.

The PDS of Helios1200 does not use a matching network as described above. Helios1200 PDS was created based on fixed match RF circuit. Basically, fixed match are designed to fit tightly the type of load driven so there is only a unique frequency. Also, the frequency signal provided by free running RF generator [6] is swept across a well-defined range to reduce the reflected power (RP). This RP is known to damage critically the PDS [6].

The two RF electrical designs have got pros and cons. Fixed match PDS is faster to reduce the reflective and offer gain from weight and cost viewpoint. However, only matching network can reduce the RP down to zero when environmental conditions change strongly. Then our design combines the best features of these two RF network designs.

3.2. Proposed fixed match automation and control

Through the means of actuators, sensors, and micro controller, the impedance of the load will be adjusted by tuning the values of the capacitors (tune and load). Those capacitance values are intended to be changed using stepper motors mounted at the end of cylindrical vacuum capacitors. In addition, the free running RF signal generator will be used to determine finely and rapidly the optimum output frequency. Figure 3 illustrates the motorization of the capacitors.

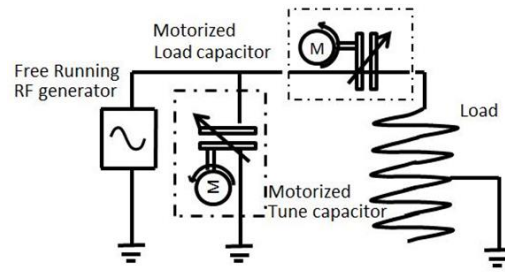


Figure 3. Motorized fixed match RF network.

4. Result

Two technical aspects of the design work were completed: electrical and mechanical design (Fig. 4).

From an electrical viewpoint, the control system hardware is defined and secured. The control system will be programmed using an open-source language based on Arduino technology. That controller will manage inputs and outputs.

The mechanical design addressed capacitor motorization, shielding of the electrical components from electromagnetic fields, and securing the position of all sensors.

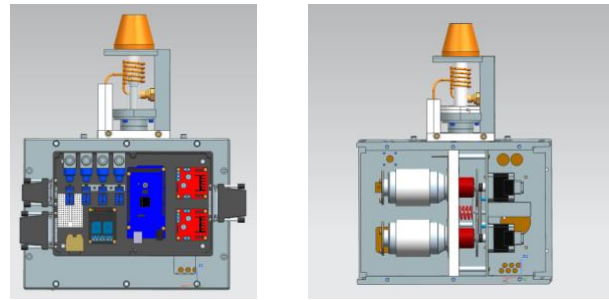


Figure 4. Electrical components (left), Mechanical components (right).

5. Conclusion

The design of a novel control system for an ICP torch was completed. A pioneering approach is being explored to enhance the processing capability of plasma delivery systems used in CNC machine tools created for high-end optical fabrication. A highly reliable and deterministic plasma processing system is expected to satisfy the needs of ultra-precision applications. Next step will focus on the fabrication and testing of this control system.

References

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