euspen's 17th International Conference & Exhibition, Hannover, DE, May 2017
www.euspen.eu

RF network parameter investigation of the plasma delivery system used for Plasma Figuring

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Abstract
The work addresses the requirement for improving the robustness and securing the performance of the Plasma Delivery System (PDS) that is used for an optical fabrication process named Plasma Figuring. This process enables the correction of metre scale optical surfaces using a plasma torch operated at atmospheric pressure. Due to complexity of interactions of PDS parameters, a one-factor-at-a-time (OFAT) method was chosen for adjusting the impedance of the plasma torch. The results show that reflected power values were less than 10 W for forwarded power values that ranged from 200 W up to 0.8 KW. The findings of the work were analysed based on ignition power demand, test repeatability and reflected power values.

Plasma delivery, plasma figuring, RF network, optimum tuning

1. Introduction

Plasma figuring process of metre-scale optical surfaces was previously achieved successfully both in terms of processing duration and form accuracy (31 nm root mean square (RMS) after 2.5 hours on a 400 mm surface) by the research team of the Precision Engineering Institute located at Cranfield University [1]. This novel and successful figuring technique is based on plasma technology. It makes use of plasma jet [2] to dry etch silicon based materials.

The current work aimed at investigating the RF network of the Plasma Delivery System (PDS). The result of this investigation enabled to determine the most influencing parameters and to recommend a method for tuning the electrical components of the plasma torch of the PDS.

The PDS was designed using a fixed match RF network and is operated at atmospheric pressure. The controlled parameters of the PDS are load capacitance, tune capacitance, and the induction coil (surface integrity and pitch). Due to effects and interactions of the parameters investigated, a one-factor-at-a-time (OFAT) method was chosen for this research work.

2. Plasma delivery system

Figure 1 shows the circuit diagram of the PDS. The PDS includes three main electrical components: RF power supply, transmission line, RF network (two capacitors and a coil). The impedance is in the form of inductance, capacitance, and resistance. The RF power supply was provided by a COMDEL CV2000/40.68 MHz RF generator. Frequency agile tuning technique is applied in this RF generator [3] to change and adjust the output frequency. Thus, the frequency range was from 38.5 up to 42.5 MHz. The RF generator has a capability to provide 2000 W and it is designed for a 50 Ohm load.

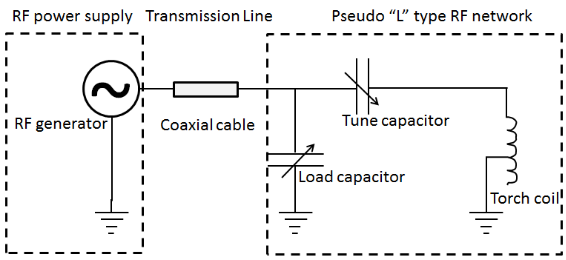

Figure 1. Circuit diagram of the plasma delivery system and its RF network

The fixed match network was carefully engineered (Figure 2) to secure the optimum performance of a bespoke inductively coupled plasma (ICP) torch. Accurate match was achieved by tuning the frequency using the Agile algorithm. This method did not completely eliminate reflected power so the RF generator was controlled on "delivered power" rather than "forward power".

A pseudo L type RF network was chosen. Indeed, the inductive output L network is able to deliver power into a relatively large output coil, limited only by practical voltage ratings of the tune capacitor and by the self-resonant frequency of the coil.

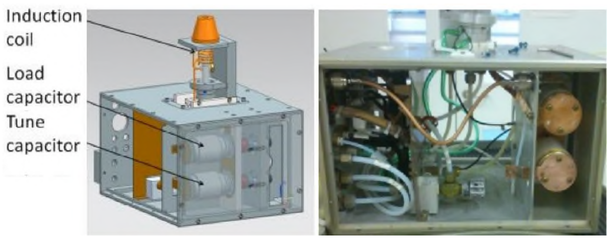

Figure 2. Schematic of the plasma delivery system and its RF network

3. Effects of tune capacitor values onto optimum frequency of RF network

The tune capacitor value was changed from 197.96 pF up to 199.50 pF (increase of 0.77%) meanwhile the load capacitor set to 27.86 pF. For each run, the plasma was ignited using a minimum amount of power ~300 W and then the RF power was increased up to 800 W. Experiments were carried out within three days.

Frequencies were recorded at both 200 W (prior ignition) and 800 W (E mode plasma). Optimum frequencies results determined by the agile technology algorithm appeared to be repeatable (Fig. 3). Maximum deviation was less than 0.1 MHz. It was observed that the logged frequency values increased when the tune capacitance value was increased. Also, a pseudo linear correlation was highlighted (dash blue and dash green lines).

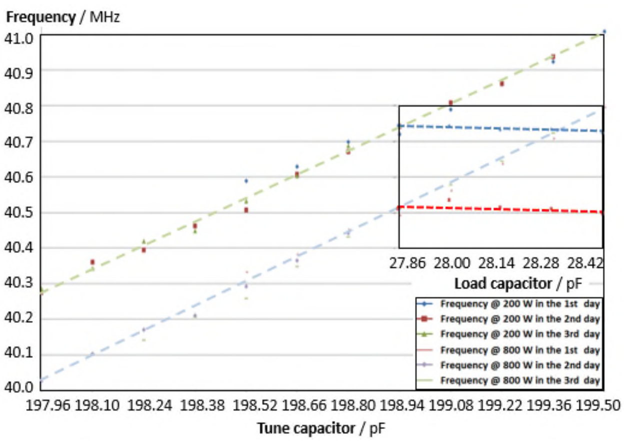

Figure 3. Comparison of influence on frequencies between tune capacitor and load capacitor

Also, the results highlighted that the tune capacitance value had stronger effect than load capacitor value. Indeed, the frequency changed by 0.05% when the load capacitance value was increased by 2%. While frequency changed by 2% when the tune capacitance value was increased by 0.77%.

4. Effects of load capacitor values onto ignition power

After setting up the tune capacitor to its believed optimum value i.e. 198.94 pF, then the load capacitor value range was investigated from 27.86 pF up to 28.42 pF. The ignition power (IP) values were systematically recorded. The IP value results are plotted in Figure 4. Solid line shows the averaged IP values. The lowest averaged IP value was achieved when the load capacitance value was set to 28.00 pF. Also, it was observed that the standard deviation value (5.75 W) had improved.

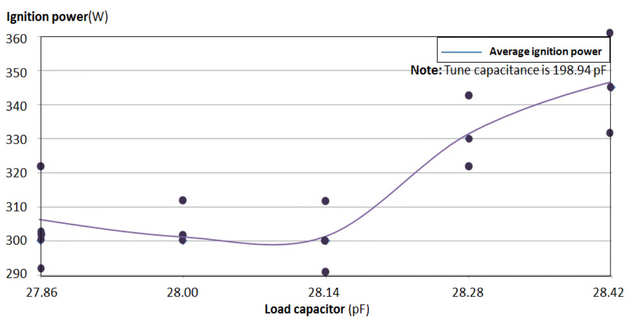

Figure 4. Load capacitance versus ignition power

5. Effects of torch coil in the RF network

The effect of changing the length of the copper coil was investigated. The length of the coil (refrigerated grade copper) was changed from 23.5 mm up to 25.5 mm. Figure 5 shows optimum frequencies for 200, 500 and 800W.

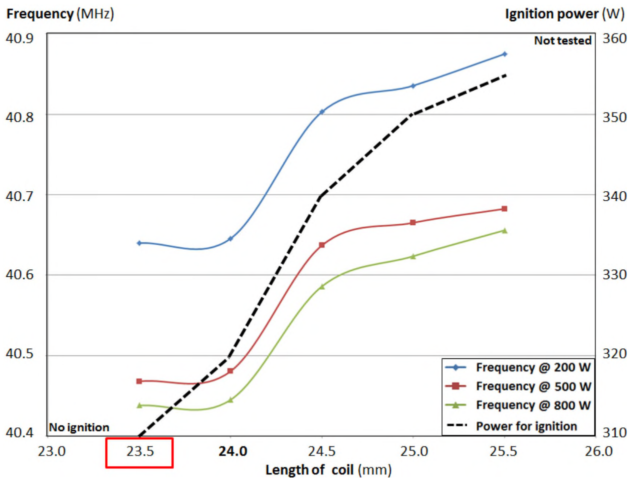

Figure 5. Frequency and ignition power versus the length of coil

Results highlighted optimum frequency shift ~500 KHz for the investigated coil length range. It was noticed that IP values were the smallest for coil length set to 23.5 mm. However, it was observed that no ignition could take place for the coil length shorter than 23.5 mm. Figure 5 shows that auto tune frequency value increases as the length of the coil increased. Also, results highlighted that ignition power value increased when coil length was increased. The reflective power values were less than 10 W.

6. Conclusion

The three variables of the pseudo L type RF network were investigated. Recommended values are given in Table 1 based on the ignition power, test repeatability and reflected power value. A correct RF network setting should enable ignition to take place at low power and reflected power to be ~0W for most RF power outputs.

Table 1 Optimum values for the RF network

Influencing factors	**Recommended value**
Tune capacitance	198.94 pF
Load capacitance	28.00 pF
Length of coil	23.5 mm

When correctly tuned the amount of power required for plasma ignition should be consistent and less than 300 W.

References

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