3D reciprocating Langmuir probe diagnostics for characteristic parameters of DC arc plasma generator in aerospace vehicles

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Abstract: A three-dimensional reciprocating Langmuir probe diagnosis and acquisition system is designed and constructed for characteristic parameters measurement of DC arc plasma generator in aerospace vehicles. It mainly includes a rail system in a vacuum chamber, a moving component system, an electrostatic probe system, and a signal acquisition and data processing system outside the vacuum chamber.

Keywords: Langmuir probe, plasma generator, aerospace vehicles.

1. Introduction

Langmuir probe, commonly referred to as electrostatic probe, is an effective technology for plasma temperature and density measurement [1]. Its theoretical basis is relatively mature, and it is widely used in various plasma devices. By observing the potential voltage and ion saturation current of the electrostatic probe, the high time resolution plasma temperature and density parameters can be simply and effectively given at a low cost. Data from a combination of electrostatic probes can also provide much more kinds of information such as electric fields, turbulent events, and the like [2].

DC arc discharge has the characteristics of easy ionization, low power consumption, high plasma temperature and ionization degree, etc., which can be applied in aerospace vehicles in various ways [3]-[5]. Although, the being developed DC arc plasma generator has been estimated approximately using a local single Langmuir probe, the testing and optimization of generator performance requires spatial distribution plasma parameters. Due to the large measurement space, the large plasma density span and the high corrosive of the solid working fluid to probes [6]-[8], the previous probe design scheme has less reference on our DC arc plasma diagnostic in aerospace vehicles. So, a three-dimensional reciprocating electrostatic (Langmuir) probe system is designed and new constructed for this purpose. It provides important basic data for the analysis and evaluation of the plasma performance in aerospace vehicles as well as the optimization design gist for the plasma generator.

2. Mechanical transmission structure

The text The three-dimensional reciprocating Langmuir probe diagnosis and acquisition system mainly includes a rail system in a vacuum chamber, a moving component system, an electrostatic probe system, and a signal acquisition and data processing system outside the vacuum chamber. Figure 1 shows the design of the linear rail inside the vacuum chamber and the moving component system. The stepping motor can precisely control the rotation speed and position. It drives the T-screw drive shaft in the middle of the base through the umbrella-shaped gear to move forward and backward. inside the vacuum chamber.

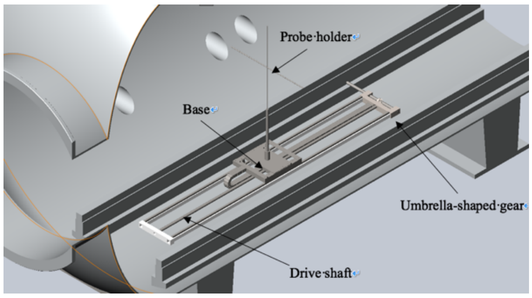

Figure 1. Rail and moving component systems inside the vacuum chamber.

The length of the guide rail is approximately 3 m and the effective shift distance of the probe holder is 2.5 m. The design of the bracket can be moved at a speed of 3 cm/s, which can meet the requirements of 3 round trips in 10 minutes. The probe holder has a width and height of 1 m and can cover the plasma core area. Due to the large space span of the entire mechanical transmission system, in order to ensure the entire system is easy to disassemble and replace, and the plasma is less affected, the components are reduced in size as much as possible. Through the simulation of SOLIDWORKS, the deformation of all components due to the gravity moment is within a reasonable range.

3. Probe measurement system

The probe system is located on a cross-shaped probe holder and can detect plasma parameters at different radial positions. The probes are evenly placed on the lateral and longitudinal supports, while the signal lines of the probe are hidden in the core of the probe holder and then introduced into the drag chain from the base of the holder. The drag chain automatically adjusts its shape as the position of the slider moves. The signal lines are all located in a closed space, which can be protected from plasma or high temperature fluids, improving system stability and reliability. After the signal line comes out of the chain, it is connected to the feed through flange of the vacuum chamber wall. On the other side of the flange, the signal and the bias of the probe are connected to the signal collector and the corresponding power source.

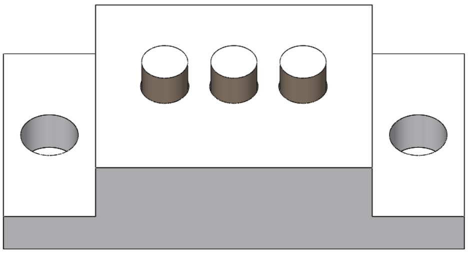

Figure 2 Overall layout of 3D probe array.

The electrostatic probe array (Figure 2) has a horizontal space of 10 cm and a total of 10 Langmuir probes in the horizontal direction with a total coverage distance of 1 m. The vertical spacing is 10 cm with a total of 10 channels, and the coverage is 1 m, too. The probe uses a three-probe design (as shown in Figure 3) that gives both electron density and temperature signals. Considering that the electron density measurement range is 10^{10}~10^{14} cm^{-3}, and the electron temperature is 5~10 eV with the working gas helium vapor (Cs133) or argon (Ar40) [9], each single probe tip is designed as a 4 mm thick and 3 mm long molybdenum rod with a total collection area of 50.2 mm-2. The ion saturation current is measured from 0.1 mA to 0.95 A (Cs) or 0.17 mA to 1.7 A (Ar). The axial direction of each single probe tip is in vertical and the horizontal spacing distance is of 6 mm.

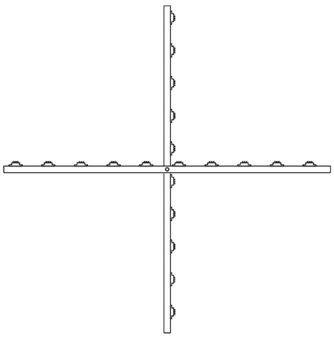

Figure 3 The structure of three-probe design.

Considering that the electronic temperature is about 5~10 eV, the DC bias power supply can be selected from a 48 V/ 3 A DC switching power supply. The voltage dividing resistor is selected as 5 Ω/20 W, and the voltage difference across the voltage dividing resistor ranges from 1 mV to 10 V (Cs) /0.5 mV~5 V (argon). The collector's input voltage is ±5 V. Taking into account the voltage value of the current bias power supply, the signal collected from the Langmuir probes is divided by the resistor into 1/10 of the original signal, and the voltage dividing resistor is selected as 1 kΩ/0.25W/1% and 9 kΩ/0.25W/1%.

4. Data acquisition system

After the signal is drawn out from the vacuum chamber through the feed through flange, the signal lines are introduced into the signal collector. Each Langmuir probes collect three signals, so a total of about 70 signals need to be acquired. The sampling rate of each acquisition is about 1 k/s. In the acquisition system, a USB multi-channel acquisition board is adopted to transmit the collected data to the host computer in real-time. In addition to receiving the data of the acquisition board, the host computer also controls the stepper motor, and the two works are collaborated together through the LabVIEW program. At the same time, the LabVIEW program will display the position information of the probe, the collected signals and the electronic temperature density information. The original signals will be stored in the form of a file to the local computer for post-processing. Before the signal acquisition, the corresponding overvoltage protection circuit will also be connected to prevent the signal collector from being damaged due to overvoltage.

5. References

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