Fusion Engineering and Design 130 (2018) 122–130

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Time resolved analysis algorithm for ramped Langmuir probe to study temporal evolution of plasma parameters in ROBIN

B.K. Das[a,*], M. Bandyopadhyay[b,c], K. Patel[c], K. Pandya[c], H. Tyagi[a], R. Yadav[a], M. Bhuyan[a], J. Bhagora[a], A. Gahlaut[c], A. Chakraborty[a]

[a] ITER-India, Institute for Plasma Research, Bhat, Gandhinagar, 382428, Gujarat, India
[b] Homi Bhabha National Institute, Training School Complex, Anushakti Nagar, Mumbai, 400094, India
[c] Institute for Plasma Research, Bhat, Gandhinagar, 382428, Gujarat, India

ARTICLE INFO

Keyword:
Langmuir probe
Plasma
Negative ion
ROBIN
Digital noise filter
LabVIEW

ABSTRACT

ROBIN (**R**f **O**perated **B**eam source in **I**ndia for **N**egative ion research) is an Inductively Coupled Plasma (ICP) device, which is powered by a 1 MHz Radio Frequency (RF) generator of 100 kW power. During the experiment in ROBIN source in IPR, plasma is monitored and characterized by two independent diagnostics based on optical emission spectroscopy (OES) and two separate Langmuir probes (LP) powered by ramped bias voltage. In the present work, an algorithm has been developed in LabVIEW to analyse the digitized LP signal to study the time evolution of different plasma parameters. The software is developed for both real time as well as post hoc analysis of Langmuir probe data and is normally applicable for low temperature, non magnetized, collisionless plasmas. The unprocessed LP data contains significant noise level and so noise filtration is adopted. In present case, Savitzky-Golay (SG) noise filtering method is used for data conditioning for its ability to preserve the area under the signal curve. The analysis software is implemented in ROBIN data acquisition setup to study the plasma evolution in ROBIN in-situ, to optimize the operational parameter regime.

1. Introduction

Langmuir probe (LP) is the most widely and frequently employed diagnostic technique in plasma all over the world due to its cost affective simple structure and well developed theory for analysis in a variety of plasmas extending from glow discharge [1] to thermonuclear fusion plasmas [2]. In its conventional structure, Langmuir probe is a thin tungsten wire inserted into the plasma which is biased with both positive and negative potential with respect to the plasma. The current drawn by the probe with respect to the different probe bias voltages, provides the valuable information of plasma such as plasma density (n), electron temperature (T_e), plasma potential (V_p), floating potential (V_f), electron energy distribution function (EEDF) etc [3]. One of the main advantages of using a Langmuir probe is that it can give local plasma parameters measurements which are often required for plasma characterization. But the current-voltage characteristics (I–V characteristics) of Langmuir probe often affected by various factors such as collisions, magnetic field, radio frequency (RF) noise *etc* [4,5]. Therefore, a number of theoretical approaches have been developed so far to understand the different parts of the I–V characteristics by the probe in different plasma regime – from ion collection regime to electron collection part. In radio-frequency (RF) plasmas, Langmuir probe is often used to determine the plasma parameters either by active [6,7] or passive compensation [8–12] of the RF oscillation. In recent years, theoretical and computational approaches have been gained considerable interest to analyse the RF contaminated I–V characteristics to obtain the original uncontaminated one [13,14]. For collisionless plasmas, the probe theory has been incessantly developed since 1926 due to the wide application of such plasmas in industrial purposes. The *orbital motion limited* (OML) theoretical approach for drifting ions towards the probe provides approximate accuracy regarding to plasma parameters for low density plasmas but its precision level significantly degrades as the density increases ($> 10^{12}\,cm^{-3}$). In this approach it is assumed that the ion current to negatively biased probe, solely depends on the angular momentum of the orbiting ions around the probe [15]. The space charge limited current to a negatively biased probe was developed in *Allen-Boyd-Reynolds* (ABR) theory for spherical probe by neglecting the ion temperature where the orbiting motion of the ions is completely neglected [16]. Afterward Chen [17] modified the ABR theory for a cylindrical probe. Stangeby [18] and Pitts [19] developed the probe theory in presence of strong magnetic field.

The computer based Langmuir probe data acquisition systems are

* Corresponding author.
E-mail address: bidyut.das@iter-india.org (B.K. Das).

https://doi.org/10.1016/j.fusengdes.2018.03.055
Received 18 May 2017; Received in revised form 10 February 2018; Accepted 24 March 2018

widely used by researcher where digitized probe data is analysed through an analysis algorithm. Such systems effectively accelerate the evaluation of plasma parameters in real time as well as post hoc analysis of probe data. Depending on different theoretical approaches, a number of analysis algorithms have been developed so far for different plasma regimes. For bi-Maxwellian plasmas, Choe et al. [1] developed an analysis algorithm based on *wavelet transform* to obtain the electron energy distribution function (EEDF). Similarly, an algorithm based on *bi-orthogonal wavelet transform* (BWT) was developed by Park et al. [20] to determine the plasma potential from the IV characteristics. The wavelet transform technique is usually applied for de-noising the probe data although digital filters are widely used for noise suppression. A simplified user friendly computer programme written in Turbo-PASCAL was developed by Neumann et al. [21] to evaluate the plasma parameters as well as the second derivative of the probe data.

In the present manuscript, a computer based data analysis algorithm has been developed for a cylindrical Langmuir probe to evaluate time resolved plasma parameters for ROBIN negative ion source at Institute for Plasma Research (IPR) [22–24], which is an inductively coupled plasma (ICP) device, powered by a 1 MHz Radio Frequency (RF) generator of 100 kW power to produce hydrogen plasma as shown in Fig. 1. The computer programme is primarily written to implement for both real time as well as post hoc data analysis of the probe IV characteristic. Initially the programme is developed in MATLAB and then written in LabVIEW following the same algorithm to interface the Langmuir probe with the existing ROBIN data acquisition system (DAS) software and corresponding hardware. The manuscript has been organized as follows. Section 2 presents a brief description about the Langmuir probe data acquisition system installed in ROBIN ion source. The smoothing procedure of the raw current and voltage signal of Langmuir probe by a digital filter is presented in Section 3. The plasma parameters evaluation procedure and its theoretical approaches are briefly described in this section. The corresponding section also includes the complete description of the complete structure of the algorithm as well as its *Graphical User Interface* (GUI) to analyse the current-voltage (IV) characteristics of Langmuir probe for both real time and post hoc analysis. The conclusion of the present work is summarised in Section 4.

2. Langmuir probe system integrated with Robin Das

2.1. Hardware

Two RF un-compensated cylindrical Langmuir probes are used with $5 \times 10-3$ m probe tip length and $3 \times 10-4$m diameter are mounted from two vertical ports placed on the top part and bottom part of the diagnostic flange of the source, as shown in Fig. 1. Two probes are installed to study the plasma density uniformity over the transverse magnetic filter field (TMF) plane, close to the Plasma Grid (PG) surface during each plasma shot. Since ion saturation data in LP's I–V characteristics is relatively less influenced by the RF field, uncompensated probes are used presently, which will be replaced by RF-compensated probes in near future. Both the probes are powered by dedicated probe bias power supply associated with specially designed front-end electronics with following characteristics. To understand the relative effect on plasma temperature; operational parameters of ramped LP bias power supplies are incorporated in analysis software. The circuit is able to provide ramped probe bias voltage from −80 V to +40 V with 10 Hz frequency and also able to support 150–200 mA of current. Such high current is expected to be drawn by the LP when positive voltage is applied on the probe to collect electrons. The electronic part also contains filter to filter out RF noise of frequencies 1 MHz and its harmonics during the measurement in floating condition, sitting on the high voltage (HV) deck in beam extraction phase also. The important components in the diagnostic front end electronics are: **(a) Triangular Wave Generator (TWG):** The TWG acts as a small signal source which generates 0–2 V of signal of 10 Hz to generate the ramped probe bias voltage. The frequency of this module can be changed by jumper settings in the circuit. **(b) Ramp Amplifier:** a circuit, based on PA 85 amplifier IC (integrated circuit), which amplifies a small signal of 0–2 V generated by a signal generator source and applies to the probe. This amplifier supports the entire current required to the probe diagnostics. **(c) Measurement sensing unit:** Since the Fiber Optic modules can support signals upto 10 V maximum, the actual voltage and current information is required to be scaled down to these levels and then transmitted. The current signal is simply converted into voltage by the potential drop across a 82 ohm resistor and then transmitted. The signals are scaled back to actual values on reaching DAS in LabVIEW platform. **(d) Fiber optic (FO) modules:** a circuit module which

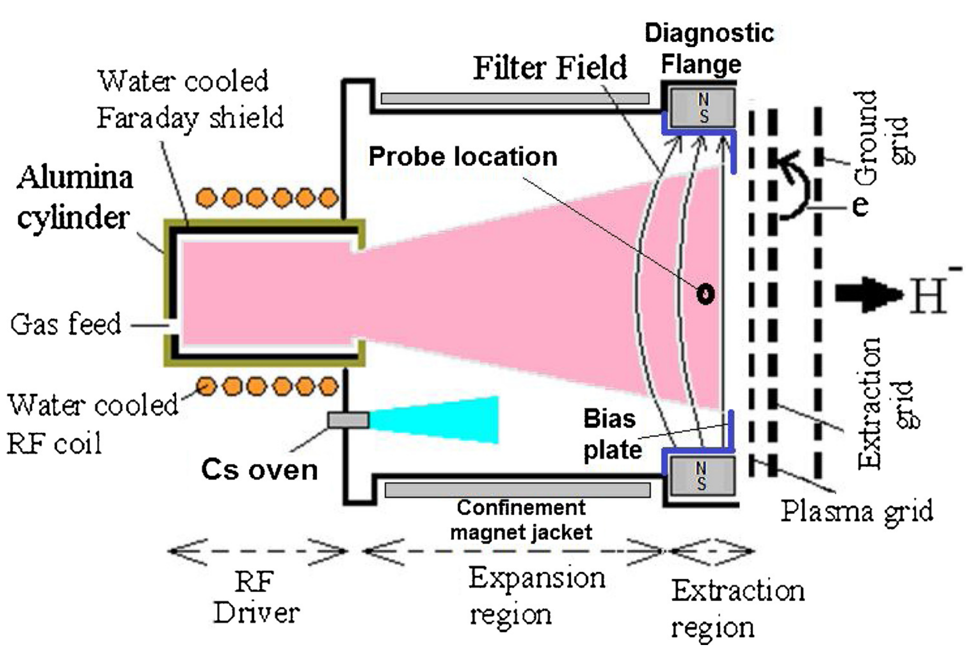

Fig. 1. Schematic diagram of ROBIN ion source at IPR, India.