

ISTTOK real-time control assisted by electric probes

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Abstract. The ISTTOK tokamak ($I_p = 7$ kA, $B_T = 0.5$ T, $R = 0.46$ m, $a = 0.085$ m) was recently upgraded with a new multiple-input multiple-output control system, where the user can specify the combination of real-time diagnostics to produce the observed plasma quantities to control any actuator. The present observed quantities are: (i) plasma current, (ii) plasma position and (iii) plasma density, all of which are actively feeded back by the system. Four-quadrant Langmuir probes were installed in ISTTOK on inner, outer, top and bottom parts of a poloidal section at a 75 mm radius. The floating potential signals measured by the four probes are fed to the control system to estimate the plasma position using a linear model. The model is based on a well known characteristic of the ISTTOK plasma, in that the floating potential varies linearly with respect to the radial position for an extension of about 10 mm (from ~70 mm to ~80 mm). By using only this set of electric probes for plasma position feedback, it was possible to obtain an alternate current (AC) discharge with 40 semi-cycles, surpassing 1 second without loss of ionization during plasma current reversal.

1. Introduction

The ISTTOK [1] tokamak (whose parameters are described in table 1) was upgraded [2] with a new control system for the automatic control of the alternate current discharges [3]. With this system it was possible to test several strategies for plasma control taking advantage of the Multi-Input Multi-Output (MIMO) [3] features installed. One of the strategies was the plasma position real-time control using electric probes. This type of control was successfully tested and demonstrated, thus providing an additional diagnostic to control the plasma position at the ISTTOK tokamak. This diagnostic can now be used as a standalone diagnostic for plasma position control or in conjunction with other diagnostics traditionally used for plasma position control.

In order to provide a real-time feedback control of the plasma parameters several diagnostics were integrated in the control system: (i) mirnov coils, (ii) tomography [4], (iii) interferometer, (iv) magnetic sine probe, (v) magnetic cosine probe, (vi) H_α radiation bolometer, (vii) loop voltage measurement and (viii) electric probes [5] which are this paper main subject.

To actuate on the plasma, several actuators were integrated in multiple a MIMO configuration; (i) two power supplies for the vertical and horizontal magnetic field based on a switching mode H-bridge with MOSFETs in parallel [6], (ii) a primary field power supply with the same characteristics as the other two but based on an IGBT H-bridge and (iii) gas injection piezoelectric valve.

The control system is based on the Telecommunications Computing Architecture (ATCA) standard [7] where two types of functional boards are used, the acquisition board and the control board. Each acquisition board includes 32 differential Analog-to-Digital Converter (ADC) channels which acquire data from the following real-time diagnostics/measurements: (i) tomography, (ii) Mirnov coils, (iii)



interferometer, (vi) electric probes, (v) sine and cosine probes, (vi) bolometer, (vii) current delivered by the power supplies, (viii) loop voltage and (ix) plasma current. On the control board, the algorithms are executed with a control cycle of $100\ \mu\text{s}$ on an IntelTM Q8200 chip with 4 cores running at 2.33 GHz. The real-time control system was programmed in C++ on top of the Multi-Platform Real-Time Framework (MARTe) [8] which is also used in several other fusion research laboratories [9].

Table 6. ISTTOK parameters.

Parameter	Value
Plasma current	7 kA
Toroidal field	0.5 T
Major radius	0.46 m
Minor radius	0.085 m

2. ISTTOK electric probes

The ISTTOK electric probes are used to characterize the plasma poloidal asymmetries [10] and are also used for indirectly estimating the plasma position by measuring the floating potential in four poloidal angles. There are four sets of electric probes installed in ISTTOK similar to the probe depicted in fig. 1. These probes are poloidally separated by 90° and are located at the top, bottom, inner and outer positions of a poloidal cross-section. The distance from the pins to the vacuum vessel centre is 75 mm while the plasma limiter is located at 85 mm from the vacuum vessel centre.

The control system acquires the data (floating potential) from one pin of each set of electric probes depicted in fig. 1. The electric probe data collection is synchronized with the control cycle which runs at a fixed period of $100\ \mu\text{s}$.

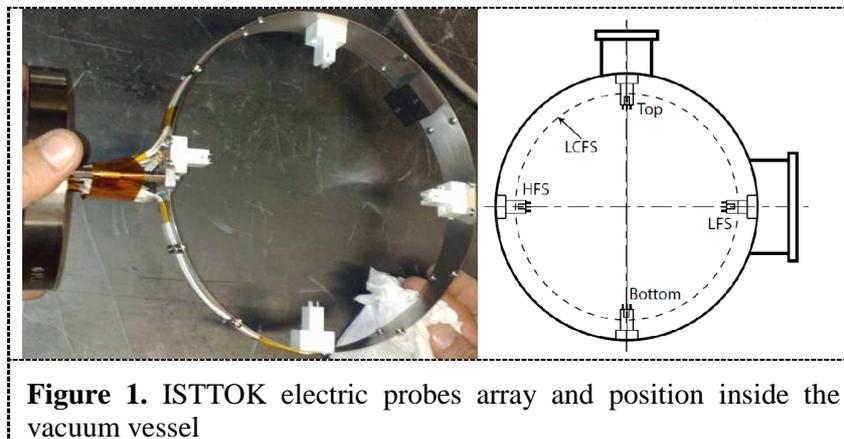


Figure 1. ISTTOK electric probes array and position inside the vacuum vessel

3. Position indirect determination using electric probes

The typical ISTTOK floating potential radial profile [11] is depicted in fig. 2. It can be observed that its value is monotonic on a region of about 15 mm inside the LCFS. Since the floating potential radial profiles are very similar for all poloidal positions, the plasma position on a given axis can be hinted from the difference between the floating potential of two opposed electric probes that define that axis. As such, the vertical position can be hinted from the floating potential measurements of the top and bottom electric probes, and similarly, a radial position estimation can be derived from the inner and outer probes

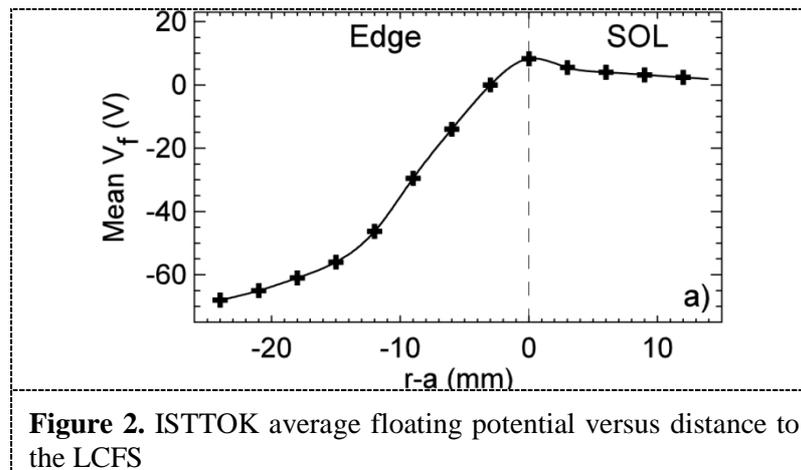


Figure 2. ISTTOK average floating potential versus distance to the LCFS

Taking into consideration the relation of the floating potential with the distance from the LCFS (fig. 2) and assuming circular plasma current only delimited by the ISTTOK inner carbon limiters, the approximate plasma position given by the electric probes is:

$$R_p = C_1 \times (V_{f_{outer}} - V_{f_{inner}}) + C_2$$

$$V_p = C_3 \times (V_{f_{top}} - V_{f_{bottom}}) + C_4$$

Where C_1 - C_4 are constants estimated from the previous characteristic (fig. 2), R_p is the plasma radial position, V_p is the vertical position, $V_{f_{outer}}$, $V_{f_{inner}}$, $V_{f_{top}}$, and $V_{f_{bottom}}$ are the floating potentials measured on the outer, inner, top and bottom probe positions respectively.

Figure 3 depicts a comparison between the radial position estimated with the electric probes and the same radial position measured by the magnetic probes. As it can be observed, apart from an offset during the negative plasma current cycles, the position obtained from the two diagnostics follows a similar pattern.

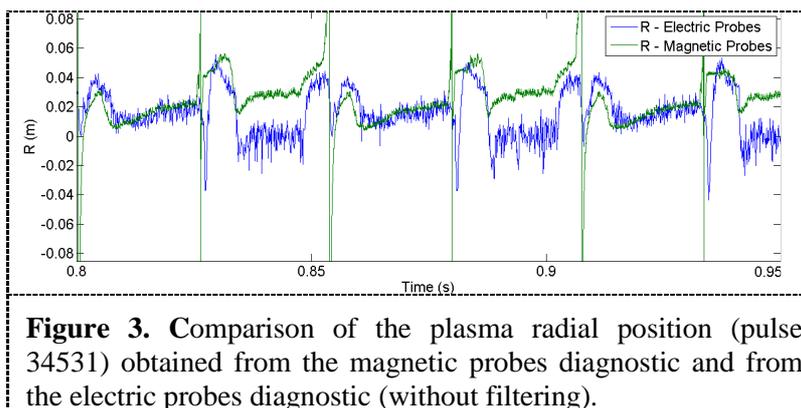
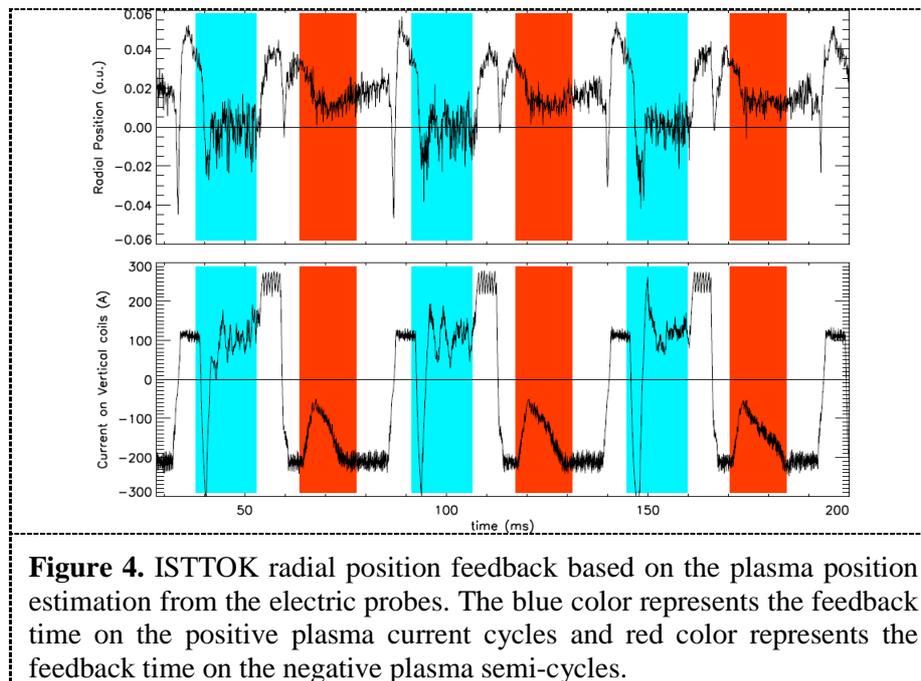


Figure 3. Comparison of the plasma radial position (pulse 34531) obtained from the magnetic probes diagnostic and from the electric probes diagnostic (without filtering).

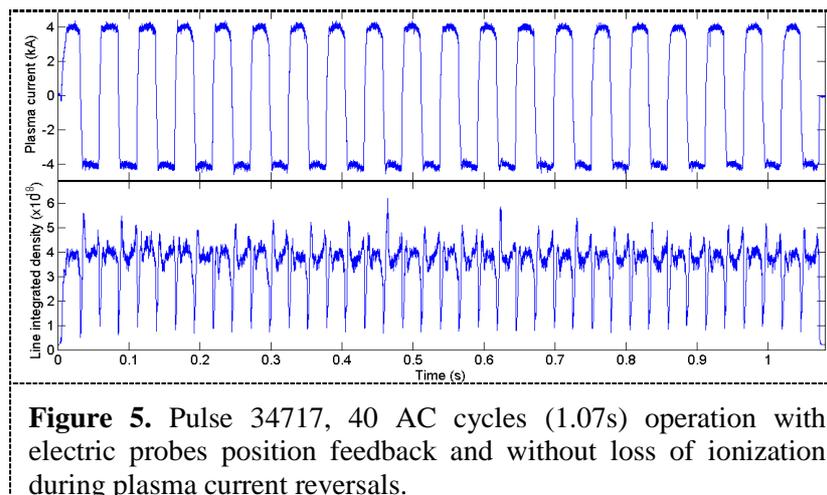
The ISTTOK control can be programmed as a mixture of feedback control and pre-programmed currents during each time-window. The fig. 4 shows the typical behavior of the vertical field coils power supply during position feedback (color shaded areas) and pre-programmed current feed to the coils (unshaded areas) using the electric probes diagnostic in real-time.



4. Results

The ISTTOK control system can be programmed to use weights for each diagnostic contribution for each plasma parameter. For the discharge depicted in fig. 4, the feedback control was exclusively done using the approximated plasma position given by the electric probes measurement.

As it can be observed in fig. 5 the feedback control of the plasma position using the electric probes enabled ISTTOK to obtain an AC discharge with more than one second of duration corresponding to 40 AC standard ISTTOK performance semi-cycles, while maintaining a finite density during plasma current reversals, as it can be observed in the line integrated density measurements from the ISTTOK interferometer.



5. Conclusions

The electric probes (as well as the other real-time diagnostics) were successfully integrated in the ISTTOK control system, providing an effective contribution for the ISTTOK real-time control, either

by using it as a standalone feedback signal or integrated in a combination of diagnostics to provide an adequate estimation of the plasma position.

The floating potential linear region probe characteristic allows for a simple model suited for real-time control to be used. The method has proved its reliability by yielding the same results as the ones obtained from the magnetic probes, with the advantage of being able to output valid plasma position estimation during the low density plasma current reversal period. This last fact revealed to be crucial to the success of long AC discharges in ISTTOK tokamak, which enables it to be used as a plasma-material interaction testing facility.

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