First measurements of the multichannel far-infrared polarimeter on RFX-mod

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Abstract. A multichannel far-infrared (FIR) polarimeter has been recently installed and improved in RFX-mod to measure the Faraday rotation angle along vertical chords on a poloidal plasma section. Polarimetric data, associated with measurements of the electron density, permit the reconstruction of the poloidal magnetic field profile, $B_\theta$. The entire diagnostic is described and its main sections outlined. Emphasis is placed on the work performed on the polarimeter to reduce the fluctuations affecting the old diagnostic signals and to increase the S/N ratio. In the recent installation of the polarimeter the optical line was more carefully designed and the mirror holders have been made in insulating material to avoid any interaction with the variable magnetic fields. Moreover all the optics have been fixed on an inertial granite platform. Examples of the first Faraday angle measurements performed on five chords are presented and discussed. The measured Faraday rotation angles are compared to a theoretically calculated value, based on the $\mu$&p model, showing a good agreement between experimental and predicted data in the central region of the plasma. The comparison between experimental and predicted data is reported and discussed in the present work.

1. Introduction

RFX-mod is the largest toroidal fusion experiment where reversed field pinch (RFP) plasmas with current up to 2MA, are studied. Since the magnetic configuration is strongly determined by currents flowing inside the plasma, an accurate measurement of the magnetic field profile is crucial to study the RFP physics. For these reasons a multichannel far infrared (FIR) polarimeter diagnostic has been installed in RFX-mod since the last year. Before this installation, an intensive activity has been undertaken to optimize the design of the new system considering several indications outlined by the previous diagnostic operating in RFX and considering the stronger operative conditions due to high plasma currents up to 2MA. The main problem in the RFX polarimeter was signal fluctuations that degraded the signal over noise ratio. The new setting has healed this problem and the system vibrations have been definitely reduced, allowing better polarimetric measurements.

In this paper, after the description of the main sections of the polarimeter, we present and discuss the experimental results of the first polarimetric measurements performed during the high current plasma campaigns.
2. Experimental set-up

The FIR polarimeter hardware consists mainly of the laser, the beam line, the beam-splitter section, the detection section, the motion electronics for the calibration procedure and the acquisition system.

The source of the laser beam is a CO$_2$ laser pumped FIR cavity (CH$_3$OH) which generates the linearly polarized radiation at 118.8 $\mu$m, mechanically chopped at 3kHz. The laser system is located in a room far from the torus and it has been recently covered by an air-conditioned box to strongly reduce the humidity in the laser room; without the dry atmosphere the radiation was attenuated up to 70% along the 2 meters long path in air between the FIR output and the optical beam line [1]. This latter guides the beam from the laser room to the beam-splitter box located close to the torus and it has a controlled Nitrogen atmosphere, as well. In the beam line, nine mirrors are displaced to lead the beam from the laser to the beam splitter box, where the FIR radiation is split into five beams by tungsten wire grids. The splitting section is integrated into the beam line and hence air-conditioned. The holders of all these mirrors are made by insulating material, whereas in the past the holder was made by metal and they interacted with the electromagnetic field, causing mirrors vibrations. Moreover, to avoid mechanical vibrations coming from the machine, the mirror holders are placed over a granite platforms.

The insulating material detection section is placed over machine and it is made up of five individual sections, each including a half wave-plate, a wire grid at 45° which divides the beam into two components and two pyroelectric detectors. These are the same as the ones used in the previous system and they have been well described in ref. 2. Each detector is equipped with a preamplifier and the signals are sent, via coaxial cables, to the diagnostic hall, where they are filtered, amplified and acquired. Then, after each plasma pulse they are processed by a software which computes the Faraday rotation angle for each line of sight. The software implements the same operations of the old hardware system [2]. It extracts the amplitude of the component at about 3 kHz (chopping frequency) from the raw signals. For each couple of detectors (named $S_A$ and $S_B$), related to the same channel, the algorithm computes the sum ($S_A+S_B$) and the difference ($|S_A-S_B|$). The Faraday rotation angle $\alpha = C \frac{|S_A-S_B|}{(S_A+S_B)}$, where C is a constant determined for each chord by the calibration procedure, afterward explained. The time resolution of the output signal is about 3ms.

The automatic calibration procedure, performed before each plasma pulse, computes the zero of the polarimeter output signal without plasma and calibrates the diagnostic before the measurement. For this purpose, each line of sight is equipped by an half wave plate, moved by a step by step motor, that rotates the polarization direction of the radiation, named $\theta$. The pre calibration performs an 80° width angular scan, in step of half degree, looking for the zero position of the output signal. Starting from the zero position of each chords, a fine scan is also performed from -10° to +10° in step of 0.1°, computing the zero position and the constant C for each chords. A diagram of the output signals $V_{out}$ versus $\theta$ allows to verify that the polarimeter responds linearly within the angular range of interest. An example of output of the pre calibration is shown in figure 1 on the left, whereas the right part of the figure shows the output of the fine angular scan.

3. First experimental results

The signal to noise ratio (S/N) has been increased by a factor three since the laser box has been conditioned and the FIR output redoubled. The whole improvements of the diagnostic and the lower level of fluctuations in the acquired signals allowed the first polarimetric measurements to be made in RFX-mod. The measurements during the vacuum shot of RFX are good with zero line very well determined and an average error of about 0.2°. In the plasma discharges a high frequency (5 kHz) noise appears on the raw signal of the detectors that are closer to the machine (the B detector of each line of sight), as displayed in figure 2. This noise, due to the electromagnetic coupling of the detectors with the radial magnetic field generated by the saddle coils of the feedback control system, seems not to affect the final result of the measurements. Even if this aspect is still being studied and not yet well understood, the reason is that the processing software extracts the component at the chopping frequency (3 kHz), deleting the high frequency noise. A typical example of measurements performed
on five chords is shown in figure 3a, where the time evolution of the polarimeter output signals during a plasma pulse is plotted for the five chords. At the end of shot when the plasma current has finished, some residual fluctuations at about 100 Hz in the polarimeter output are still visible with less impact on the measurements than in the past. The origin of these noise is purely mechanical and so they should be strongly reduced with a better alignment and a higher radiation power which has been achieved after the laser maintenance.

The Faraday angle measured by the polarimeter has been compared to the theoretically calculated values based on the μ&ρ model [3] and on the interferometric measurements. The magnetic field and the inverted electron density radial profiles allow to compute the theoretical Faraday rotation angle along the minor radius of the torus and its temporal evolution. An example of the comparison of the measured and predicted data is given in figure 3b, where the Faraday rotation profile as a function of the distance of the chords from the centre of the vessel is shown. The measured and the predicted data are in good agreement having the same order of magnitude and following the same general profile shape. The differences increase going from the centre towards the edge highlighting how the μ&ρ model is not able to describe the actual magnetic profiles especially in the edge of the plasma where the electron density and current density gradient are present. Hence a deeper study of the internal current density profile is currently being performed. The graph also reveals that the experimental values do not pass through zero at the centre of the vessel, performing an experimental determination of the position of the magnetic axis in RFX-mod, that is clearly displaced towards the outer edge of the torus [4]. The shift

**Figure 1.** Example of the output of the pre calibration procedure (left side) and of the fine calibration procedure (right side) for chord #5.

**Figure 2.** (a) signal from detector B of chord #3 (shot 26555) and (b) with 5 kHz noise (shot 26547)
of the plasma has been investigated in RFX-mod by soft X rays tomography and the preliminary data of the polarimeter are in agreement with the SXR measurements [5].

4. Conclusions and further developments

RFX-mod is now equipped with a multichord FIR polarimeter for measurement of the Faraday rotation angle. Faraday rotation measurements have been obtained in high current (Ip > 1.5 MA) pulses obtaining values from zero up to more then 15°, with a good level of signal over noise ratio. The preliminary results highlighted the shift of the plasma magnetic axis and the measured values agree with those computed by other diagnostic. The comparison with a theoretical model for the determination of the internal magnetic radial profile shows a general good agreement, whereas the main differences are in the edge region of the plasma. A more suitable description of the internal magnetic profile is being studied. Still some improvement on the diagnostic are needed. In particular, increasing the S/N with a new setup of the beam splitter box and of the detection section will help to obtain a better alignment of the laser beam. A noise on the raw signals of some detectors is present and an electromagnetic screen or a displacement of the detectors is under investigation.

It can be concluded that in the present state the polarimeter diagnostic is capable of giving a valid contribution to the knowledge of the RFX-mod experiments in combination with other diagnostics.

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