Polarization Issues with High Power Injection & Low Power Emission in Fusion Experiments

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Abstract. All tokamak experiments using ECCD require setting of the beam elliptical polarization for proper coupling to the plasma. This is done either in the matching optics unit (MOU) at the output of the gyrotron, or in a couple of miter bends of the transmission line. Similarly, oblique ECE receivers require selection of the correct elliptical polarization to provide localized measurements. For the TCV tokamak at the CRPP, gyrotron and oblique-ECE polarizers are characterized during either high- or low- power testing of equipment: for the gyrotrons the behaviour is determined at a single frequency, but for the oblique-ECE the broadband response is needed. These characteristics are included in the calibration database and used during subsequent analysis of the power coupling to, or from, the sources (gyrotron, plasma, or low power transmitting antenna). A more detailed characterization has been carried out (at low power) with the MOU for the EU, 170GHz, 2MW, gyrotron prototype for ITER. This paper discusses the methodology and results of these measurements, as well as a review of nearly a decade's worth of experimental data from the 6 gyrotron, 3MW, 82.6GHz TCV system. In particular, the consistency between the calibrations and the subsequent data from tokamak experiments is analysed.

Keywords: Polarization, 170GHz, MOU, RFCU, Oblique ECE, plasma, TCV, ITER

INTRODUCTION

The Tokamak à Configuration Variable (TCV) 2nd harmonic ECH system (82.6 GHz) is equipped with 6 gyrotrons of 0.5 MW power each. The power is injected in the plasma via 6 steerable launchers with 2 degrees of freedom each. Four launchers are located in upper lateral ports of TCV vacuum vessel and two in equatorial ports. One of the injection angles can be programmed to change during the plasma discharge with feed-forward or feed-back commands. The plasma shaping parameters and magnetic axis location can be varied as well over a large range as can the magnetic field and plasma current, all during a shot. All of these variations can affect the injected EC beam polarization that is required to optimally couple to the quasi X-mode at the plasma edge, for example.

Present day tokamaks typically inject beams with the polarization constant during the shot, but adjustable between shots. For most experiments this is sufficient as the changes in the required polarization lead to only a small fraction of power coupled to the 'wrong' mode as the plasma changes.

On the other hand, as pulse lengths become longer, it is more important to avoid even small fractions of wrong modes as these tend to be poorly absorbed or reflected and can, over time, lead to overheating of plasma facing elements or diagnostics.

On TCV it is planned to install fast polarizers allowing a change in the polarization of the injected beams within the 2s pulse lengths of the gyrotrons. Methods of wrong mode detection and polarization optimization will be investigated for a variety of heating schemes and these plans have led to a simple investigation of the sensitivity of our system to the potential changes in coupling. This work complements present collaborations with other laboratories around the world and is directly relevent to future ITER experiments.

MODELING OF POLARIZERS AND EXPERIMENTAL CONFIRMATION

Modeling of the polarizing action of polarizers is carried out by all experimenters in plasma physics when installing EC systems. Typically, measurements are used to confirm the models prior to use in the plasma experiments e.g. [1], usually include confirmation after a transmission towards the plasma e.g. [2], [3], and may include measurements of plasma reaction to the heating e.g [4].

On TCV, once the plasma configuration and launching angles are programmed as a function of time, the intersections of the beams and the plasma edge are determined and the required polarization is calculated as it would be needed at the entrance to the launchers (for the desired mode – X or O). The modeled transfer function of the polarization from the MOU (where it is set) to the entrance of the launcher, as a function of the polarizer angles, is used in a non-linear minimization search to minimize the sum of the squares of the required $\alpha_{req.}$ minus the set α_{set} (polarization rotation) and of $\beta_{req.} - \beta_{set}$ (polarization ellipticity). Since the polarization is constant during the shot, this optimization of power coupling can only be carried out for the plasma / launch configuration at one particular time (more details of TCV EC operation are given in [6]). Once the MOU polarizer angles are chosen, the power-coupling fraction between the elliptically polarized beam and the linearly-polarized forward-power receivers (attached to a power monitor miter bend, PMMB, in each transmission line) is stored in the shot data. This factor is used to 'correct' the received signal to produce a 'forward power', P_{for}, independent of the polarization.

The calorimetrically determined power is measured as a function of the gyrotron operating parameters - in particular the cathode voltage, V_k when the gyrotrons are installed (and is checked periodically). The coupling of the PMMB and the 'zero' angles of the MOU polarizer mirrors are determined using detailed scans of the angles during constant power pulsing of the gyrotrons. Figure 1 shows the MOU, a typical polarization ellipse, and a set of data in which several different polarizer angle combinations, but constant input power, have been used to calibrate the MOU and PMMB. The modelled power is plotted against the measured power; the green circles are prior to 3-free-parameter fitting of the data and the red asterisks are after fitting. The fit parameter values for the two MOU 'zeros' are listed in the plot title and the fit value of the maximum power measurable by the receiver for the given input power is given in the abscissa label.

With these calibrations it is possible to compare P_{for} with P_{V_k} for the entire TCV EC database covering nearly a decade. Figure 2 shows the ratio P_{for}/P_{V_k} as a function of shot number for the six X2 transmission lines; the ratio should be one if this method

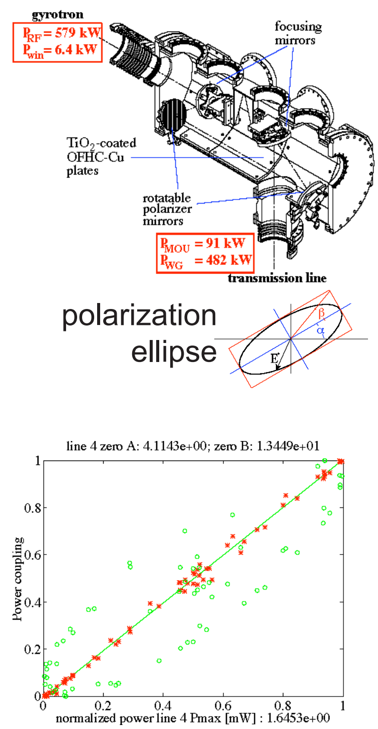

FIGURE 1. MOU / PMMB calibration The MOU with 2 polarizer mirrors, the polarization ellipse and fitted calibration data for the mirror angles and power coupling. Random combinations of grating angles are usually used for this calibration.

of measuring the forward power is reliable. The colors correspond to the years 2000 to 2007. P_{V_k} has been found to be very reproducible as we operate at the point of maximum power output for the gyrotron (i.e. constant cathode current and magnetic field). The data show that P_{for} cannot be used reliably as a measure of the injected power: the statistical variation within each year is large and there are slow trends over time for some transmission lines. No correlation with the α_{set} nor β_{set} has been found.

It was known early on that the P_{for} time-trace is not 'flat' for constant V_k. This is consistent with the facts that (1) the frequency of the X2 gyrotrons drifts continually during the 2s pulse, and (2) there is a mixture of modes in the transmission line which allows the footprint of the beam on the mitre bend coupling holes to change, affecting the power coupling to the receiver without affecting the power transmitted to the plasma (or calorimetric load). Nevertheless, that the P_{for} cannot be used even in an average sense is surprising because average-power measurements from the PMMB are precisely those used to perform the MOU and PMMB calibrations. These results, in particular the shot-to-shot variation within one year, will be the subject of further off-line (load) and on-line (plasma) investigations in the near future.

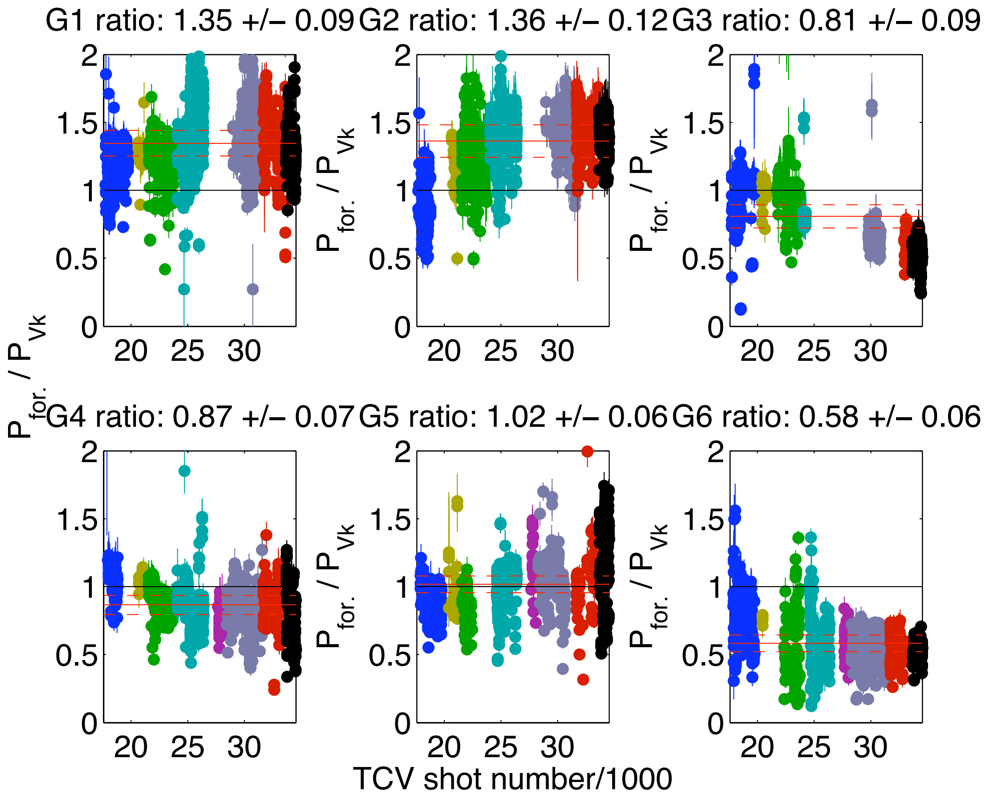

FIGURE 2. Power measurement ratio: 2000-2007 The ratio of P_{for}/P_{V_k} for shot numbers of the years 2000 through 2007 show a large scatter within each year and mild trends from year-to-year. Years are indicated by different colors, errorbars indicate the standard deviation of the ratio during a single shot.

MOU POLARIZER FOR ITER 170GHZ, 2MW, EU GYROTRON

The polarizer in the MOU of the EU ITER gyrotron has been used at low power, allowing thousands of polarizer angle combinations to be tested in a short time. Figure 3 shows one 2D scan of the polarizer angles, comparing the modeled and measured signals. The data is plotted in a manner similar to that in figure 1, for comparison.

FAST POLARIZERS - FUTURE EXPERIMENTS

In future fusion experiments, such as ITER, methods of detecting stray (non-absorbed) power will be required to protect equipment. The TCV pulse length is 2s and therefore, unlike steady-state experiments such as LHD, the EC system will require a fast-polarizer to permit real-time methods to be investigated. To this end, we have purchased fast (0.1s) miter bend polarizers from General Atomics. These will be tested first at low power (as a complementary experiment to work being done in collaboration with LHD [5]), then installed in one transmission line of TCV. Using the present stray power detectors installed on the TCV vessel, we expect to be able to validate the optimized coupled

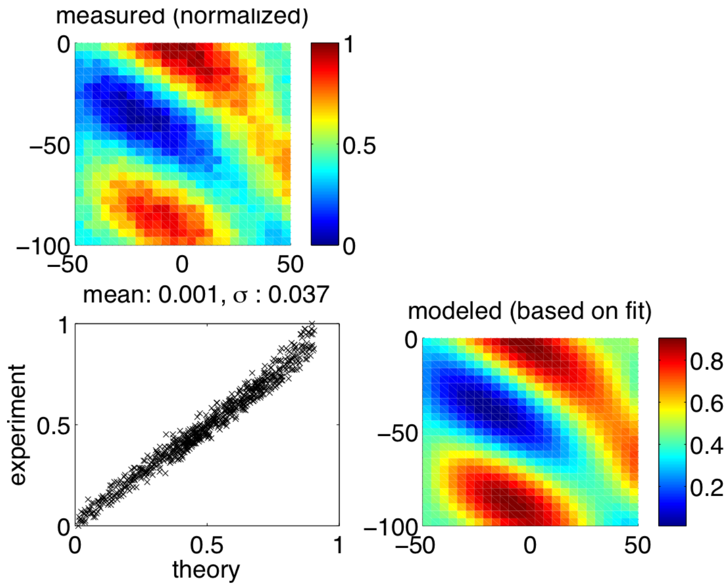

FIGURE 3. ITER EU MOU data Comparison of the modeled and measured coupling to linear receiver after the ITER EU MOU for a full range of polarizer angles. Color contours indicate general good agreement while the standard deviation from a straight line is indicated in the title of the plot at the lower left.

power calculations and characterize the signals to be used for real-time feedback control of the polarization.

One example of the use of the fast polarizers is shown in figure 4, in which both polarizers are rotated by up to $\pm 10^o$ in such a way as to produce a constant α but a sinusoidal β oscillation at 10Hz – in order to vary the power coupled to the quasi-O mode. The simulation is based on shots from previous O-X-B experiments in which the detected stray power was used to optimize the launcher angles [7]. It shows that the coupled power would range between 85% and 100%. Initial investigations will determine whether such a variation is detectable and can be used for real-time optimization experiments (one obvious option to 'enhance' the stray signal, would be to permit α to change as well).

Similarly, the same polarizer setup can be installed in the front-end of the oblique ECE (ObECE) antenna used on TCV [8] which also incorporates 63.5mm diameter waveguide, like the transmission lines. This antenna has been used previously to sweep the ECE *viewing line* across the plasma cross-section. For optimum X-mode viewing at a fixed frequency, the polarizer would need to be adjusted as a function of time (for either launching or receiving since the antennas are identical). This is easily achievable given the speed of the polarizers.

Finally, for a fixed angle of view, the ObECE antenna in conjunction with the fast polarizers can scan the plasma cross-section radially by providing optimum X-mode viewing at the center frequency of two narrowly-separated correlation ECE channels whose center frequency is swept. Preliminary estimates indicate that the polarizer angles will likely need to change on the order of $\sim 10^o$, which will allow several scans during a 2s pulse (see figure 4).

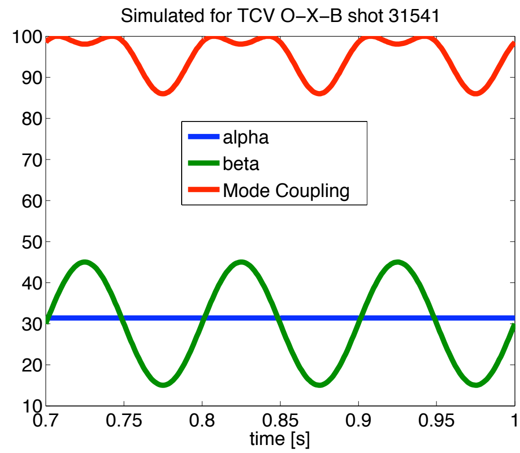

FIGURE 4. Fast Polarizer Simulations: EBW example The polarizers are moved $\pm 10^o$ at 10Hz to maintain constant α but oscillatory β angles, causing the simulated mode coupling to drop by up to 15%.

CONCLUSION

At TCV the gyrotron power calibration is calculated from the cathode voltage as the forward power measurements of elliptical polarization coupled to a linear receiver show excessive variations, unlike the ITER MOU polarizer at low power. New fast polarizers, soon to be installed in one transmission line and subsequently at the radiometer front-end, will allow a variety of novel experiments to be carried out in the coming years.

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