POLARIZATION MEASUREMENT IN THE 118 GHZ TRANSMITTER OF TORE SUPRA

G. Berger-By, M. Lennholm, J. Achard, F. Bouquey, J. Clary, C. Darbos, M. Jung, R. Lambert, R. Magne, D. Roux, E. Traisnel

Association EURATOM-CEA, CEA/DSM/DRFC CEA-CADARACHE, 13108 ST PAUL LEZ DURANCE (France)

e-mail: gilles.berger-by@cea.fr

Since 1994, an Electron Cyclotron Resonance Heating and Current Drive System (ECRH/ECCD) 118GHz-2.4MW-10min, is under development for the Tore Supra (TS) tokamak [1]. The antenna has three plane mobile mirrors to control toroidal and poloidal injection angles of the beam. The polarization control system is located at the gyrotron output in the MOU (Matching Optic Unit) after the cryogenic window. This MOU allows complete control of the polarization of the wave using two corrugated mirrors. Ordinary mode (O mode: E // Bt) injection is used on TS at the maximum toroidal field; by reducing the toroidal field extraordinary mode (X mode: E ⊥ Bt) can also be used. To study: transport, MHD control, co-current and counter-current ECCD, synergy heating and current drive with Lower Hybrid waves in plasma experiments, it is important to change the power deposition profile by adjustment of the injected beam direction [2]. Thus, the polarization of the injected beam is a function of four parameters: the two polarization mirror angles and the two injection angles. We can calculate, for each set of injection angles, the required settings for the 2 polarization mirrors to achieve the desired polarisation of the injected wave [3]. In the present TS ECRH power measurement system, situated after the polarization system, only one electric field direction is measured [4]. In order to always have a good signal/noise ratio when we change the polarization, we must turn the rectangular measurement horn by 90° in certain cases. As a consequence, we have three difficulties: this intervention is not practical, not very reproducible and the coupling in the two directions is different. This leads to doubts about the injected power when we change the polarization and a difficulty to test X mode or O mode. In order to improve the precision of the beam injected in the plasma we have: measured the transfer function of the MOU in laboratory, compared it with the calculation using a code developed in CRPP Lausanne and designed a new power measurement system for measuring simultaneously the amplitude of the vertical and horizontal component of the injected power . We explain the principle of the MOU measurements performed with a mode converter and a network analyser (ABmm) and discuss the comparison with theory. The principle of the double polarization measurement system is described including: the laboratory checking, the calibration principle, and the electronic design.

1- INTRODUCTION

The polarization control system is located at the gyrotron output in the MOU and after the cryogenic window. This component is critical to achieve a good power transmission between the tube and the antenna. In addition, it permits complete control of the polarization of the wave coupled into the transmission line. Its transfer function has been calculated by a code developed in CRPP (Lausanne) and modified on TS [3]. This code contains some approximations for the calculation. In order to assure that we have the correct polarization at its output, we have measured the transfer function of the MOU. The control of the polarization of the injected wave is a concern for us in each physics experiment. Therefore we have improved the present measurement system by the design of a new prototype for the power measurements with the capability to measure the amplitudes of the horizontal and vertical component of the injected power simultaneously.

2- MEASUREMENT OF THE MOU TRANSFER FUNCTION IN LOW POWER LABORATORY

2-1 MOU principle

The MOU is evacuated and water cooled, it has 3 mirrors: M1 corrugated plane at $\lambda_o/8$, M2 corrugated plane at $\lambda_o/4$ and M3 bi-parabolic (λ_o=vacuum wavelength = 2.54 mm for 118GHz).

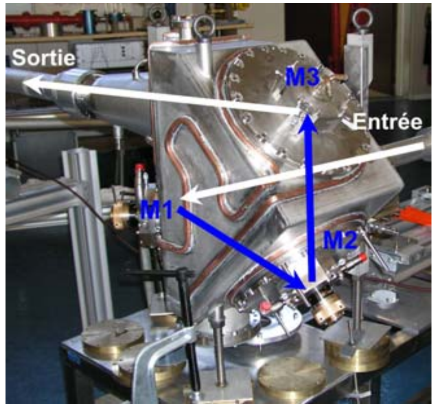

Fig 1: The MOU mirrors M1 M2 M3

The 2 mirrors M1/M2 make up the polarizer, they can be rotated and adjusted in 2 directions (X,Y). The M3 mirror can be adjusted in 2 directions in order to focalise the beam in the standard output waveguide in HE11 mode (Figure 1).

2-2 Definitions and terminology used

Polarization direction:

$$\beta = \text{Arctg}(Ey/Ex) \quad (1)$$

Polarization ellipticity:

$$\gamma = \text{Arctg}(Ey'/Ex') \quad (2)$$

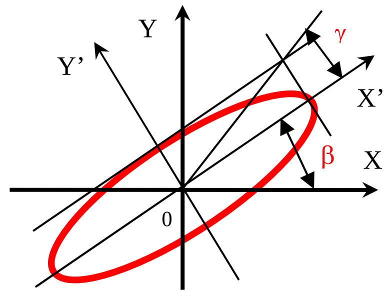

Fig 2: Polarization angles

M1 allows adjustment mainly of the ellipticity (γ) while M2 allows adjustment mainly of the direction of the main axis of the polarization ellipse (β), but for an optimum adjustment the 2 mirror positions are linked.

2-3 Measurement principle

The MOU is a heavy component and requires a special support and a lifting apparatus. A mechanical set up to support and to align very precisely all the components with a laser has been designed (Figure 3).

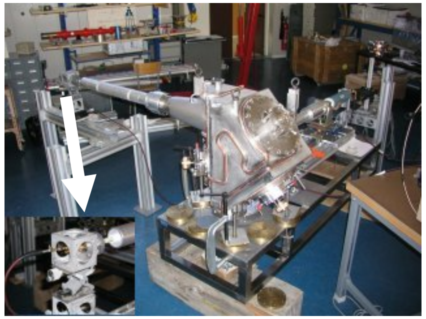

Fig 3: The MOU measurement test set

The circular measurement horn is placed on a micro-control rotating support in order to take the measurements in 2 directions at 90°. The horn centre is adjusted in front of the MOU output waveguide centre with a double stage micro-control XY (Zoom figure 3). A mode converter □ 1x2mm TE10 / HE11 ϕ=63.5 mm replace the gyrotron beam (Figure 4). The length (D) between the excitation waveguide output and the first mirror M1 is adjusted in order to have the same waist on the first mirror as for the gyrotron beam. In figure 5, the propagation of the gaussian beam at the output converter is plotted with the gyrotron output beam as calculated by a Thales Electron Devices (TED) code. This has allowed us to determine the best choice for D.

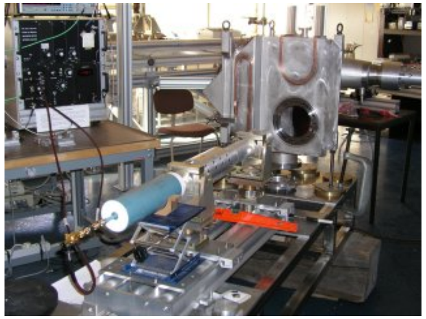

Fig 4: The excitation principle with the TE10/HE11 mode converter

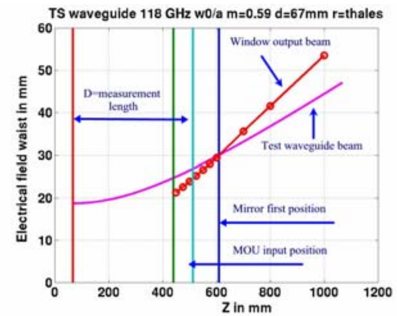

Fig 5: Measurement length calculation

The measurement is made with our ABmm network analyser, the generator head is connected to the input mode converter and the measurement head is connected to the rotating measurement horn placed at the output of the MOU. The ABmm network analyser is used with a constant frequency or with a frequency sweep from 117.5 GHz to 118.5 GHz. The network analyser frequency is locked to an EIP counter in order to have the best frequency stability and accuracy.

The measurement method is the following : For a given ellipticity (γ) and a direction (β), the theoretical positions M1-M2 are calculated with the code.

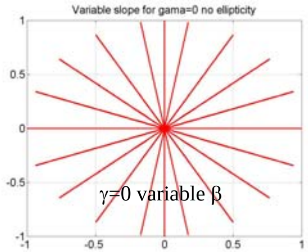

Fig 6: Linear polarizations

These values are set on the MOU mirrors and the amplitude and phase for 2 perpendicular directions are measured with the rotating measurement horn.

We have tested 3 different situations. The first was for linear polarizations γ=0, varying the polarisation direction from β=0 to 180° (Figure 6), the second was to look for the best adjustment of the 2 mirrors for a perfect linear polarization and the third was for elliptic polarizations with β=0 and variable ellipticity (Figure 7).

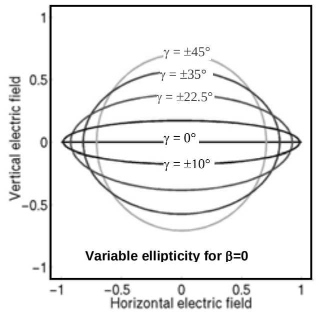

Fig 7: Variable ellipticity for β=0

The results of these 3 measurement situations are summarized in the 3 following paragraphs.

2-4 Results in linear polarizations

The 2 components E^2x, E^2y are plotted in figure 8 versus the direction of the electric field fixed by the 2 mirrors positions. The measurements are converted from dB into linear scale and normalised. The direction calculated with (1) is plotted in figure 9.

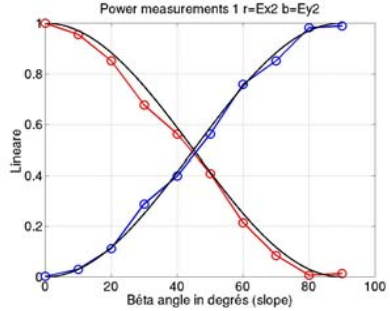

Fig 8: Amplitude measurements

A very good agreement with the theoretical responses in $\cos^2(\beta)$, and $\sin^2(\beta)$ and arctg(Ey/Ex) is found. In figure 10 all these measurements are summarized and the conclusions are that the measurements agree with the theoretical and that the calculated mirror positions are correct with a maximum ellipticity error=±5°.

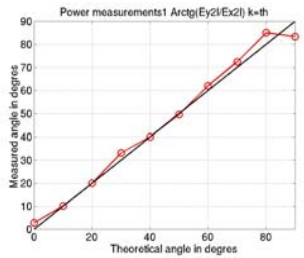

Fig 9: Calculated phase

There is no significant variation with the frequency change (118-117.5 GHz) corresponding to the gyrotron frequency shift at the start of a pulse.

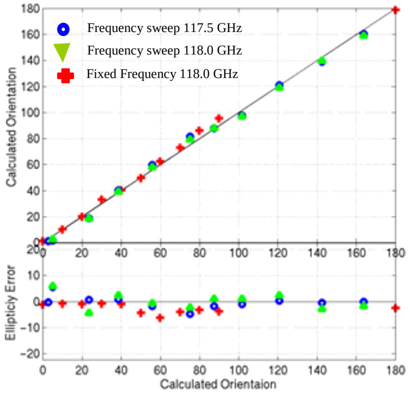

Fig 10: Linear polarizations

2-5 Results optimised positions in linear polarizations

In this experiment we have attempted to optimise by successive approximation the 2 mirror positions to achieve minimum power in the direction perpendicular to the desired direction.

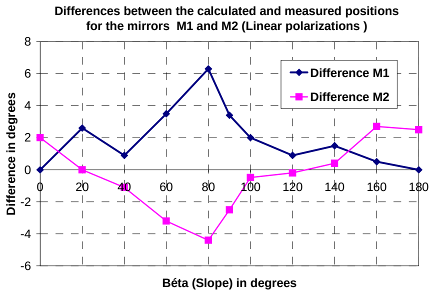

Fig 11: Calculated/measured differences positions for M1 and M2 (F=118 GHz)

In figure 11 the differences between the optimum positions found in this way and the calculated positions for the 2 mirrors M1/M2 are plotted for the different linear polarizations tested. The calculated and measured positions are very close, with a maximum error of 6° for M1 and 4 ° for M2.

2-6 Results in elliptic polarizations

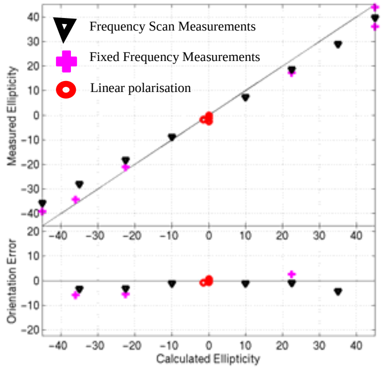

Fig 12: Measurement in elliptic polarizations at 118 GHz

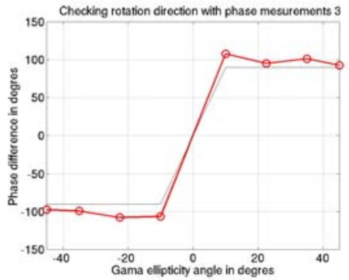

Fig 13: Checking the rotation direction with phase measurements of E^2x E^2y

In figures 12-13 the measurements are seen to agree with the calculations and the conclusions are that the calculated mirror positions are correct with a maximum direction error=±5° and a right rotation direction.

3- POWER MEASUREMENT IN 2 DIRECTIONS

3-1 Millimetric principle

In the gyrotron power measurement system, we are replacing the rectangular horn of the forward power measurement mitre bend by a circular horn with an orthomode transducer in F band. In order to have the best signal to noise ratio, level set attenuators are used before the detectors with preamplifiers to adjust the coupling at the same value and to use the detectors quadratic measurement region (Figure 14).

These systems use many millimetric components developed by ELVA-1 (St Petersburg Russia) circular horn, wave guide transition, orthomode transducer, attenuator, detector, coupler… and a HE11 mode converter from IAP (Institute of Applied Physics Nizhny Novgorod Russia) for calibration.

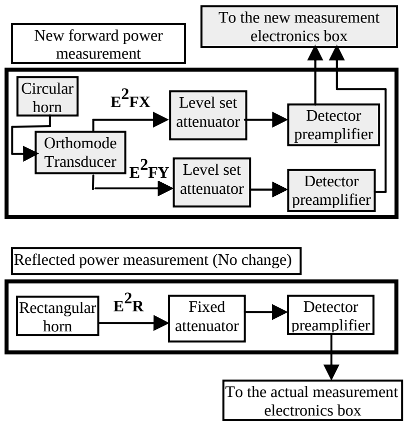

Fig 14: Measurement system principle

3-2 Orthomode transducer measurement - low power test

Using the ABmm network analyser we have verified the transfer function of the orthomode transducer. A TE11 beam is injected with a □ TE10/ O TE11 transition and a circular horn (ϕ_{in}=1.91 mm ϕ_{out}=12mm) to the orthomode transducer input (Measurement length D=200mm) equipped with the same circular horn. In figure 15 the 2 components E^2x, E^2y are plotted versus the direction of the electric field injected at the input. We observe a very good agreement with the theoretical responses in $\cos^2(\beta)$ and $\sin^2(\beta)$.

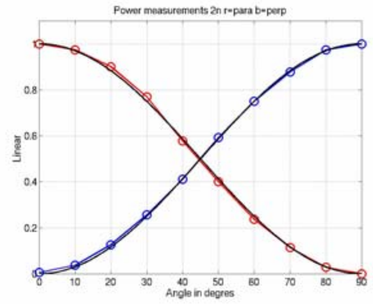

Fig 15: Orthomode transducer transfer function at 118 GHz

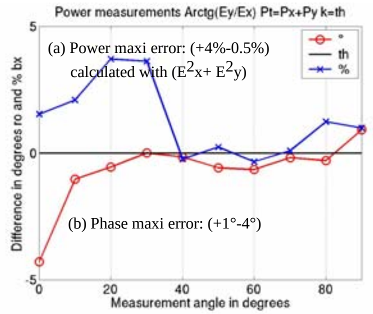

Fig 16: Power and phase errors

The accuracy of the total power calculated is plotted in figure 16a, the phase difference between the input polarization direction and the calculated one with the 2 power measurements is plotted in figure 16b. These measurements prove that this orthomode transducer can measure the total power and the direction of the polarization with sufficient accuracy.

3-3 Electronic principle

The same electronic cards as in the present measurement systems have been used [4]. A differential amplifier has been used after the detectors with preamplifiers to set the same sensitivity for the 2 channels. A test generator which simulates in pulses (T=10ms duty cycle 50%) the 2 signals originating from the detectors is used to check all the measurement circuits. The signals are converted into isolated 4/20mA with a 2nd order low pass filter (Bandwidth 400Hz) for sampling at 1ms without aliasing. In order to assure that the measured signals are in the correct range 2 thresholds (minimum and maximum) are implemented. If these thresholds are exceeded security output signals are generated. These security output signals are isolated by optocoupler for correct transmission to the Gyrotron protection state machine. The new measurement system is installed in a new cabinet (Air cooled and with a good EMC) placed near the modified measurement mitre bend (Figure 17).

Fig 17: The electronic cabinets

3-4 Calibration principle in laboratory

The mitre bend coupling values are measured with a HE11 mode converter and the ABmm network analyser. An external Gunn oscillator locked on the analyser is used in order to achieve a 130dB typical dynamic range at 118GHz. The passive component attenuations are adjusted to compensate for the coupling differences. Every detector and all the electronic circuits up to the acquisition are subsequently adjusted and calibrated at 118 GHz with our special hardware and software for automatic calibration. Consequently, all measurement channels have the same transfer function.

3-5 Measurement in the transmitter

This system will be used on the new series gyrotron (Third TS gyrotron) during the tests on load before the routine use on TS plasma shots planned in the autumn. The 2 millimetric measurements will be compared with the thermal measurement once gyrotron testing starts. Using the low power laboratory MOU calibration and the polarisation calculation code, we will change the 2 mirror positions (M1-M2) to have different linear or elliptic polarizations. The MOU can be verified at high power using this new measurement system. The power stability during polarization changes can also be studied.

4- CONCLUSIONS

The MOU has been qualified in the TS millimetric laboratory with low power and different polarizations. In linear polarization the maximum ellipticity error is below 5° and in elliptic polarization the maximum error of the polarisation direction is below 5°. The 2 mirror positions M1 and M2 calculated by the CRPP (Lausanne) code modified on TS have been compared to the best settings found in the laboratory for linear polarization and the differences are below 6° for M1 and 4° for M2.

The prototype of the new gyrotron power measurement system will allow: to measure the direction of the polarization at the MOU output and to calculate the total power injected to the TS plasma. This system will be tested on the new Thales gyrotron in current tests on the TS transmitter [5].

REFERENCES

[1] Pain M. et al "Status of the ECRH system of Tore Supra" *Proceeding 18th SOFT (Karlsruhe*) pp481-4 (1994).

[2] G. Girruzzi et al. "Current profile control by electron cyclotron waves in non-inductive plasma regimes on Tore Supra" *30th EPS Conf. On Controlled Fusion and Plasma Physics* (2003).

[3] M. Lennholm et al. "The ECRH/ECCD system on Tore Supra, a major step towards continuous operation" *Nuclear Fusion*, vol.**43** p1458-1420 (2003).

[4] G. Berger-By et al. "The power measurement system of the Tore Supra ECRH transmitter at 118 GHz", *12th Joint Workshop on ECE and ECRH* (Proc. World Scientific (2003) p.579-584) (2002).

[5] C. Darbos et al "New design of the gyrotron used for ECRH experiments on Tore Supra", *this EC13 conference.*