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CALIBRATION OF FABRY-PEROT INTERFEROMETERS FOR ELECTRON CYCLOTRON EMISSION MEASUREMENTS ON THE TORE SUPRA TOKAMAK

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Calibration of Fabry-Perot interferometers for electron cyclotron emission measurements on the TORE SUPRA tokamak

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ABSTRACT

The electron temperature is routinely measured on TORE SUPRA using Fabry-Perot cavities. These have been calibrated using a technique involving coherent addition and Fourier analysis of a chopped black-body source. Comparison with conventional techniques is reported.

INTRODUCTION

In the TORE-SUPRA tokamak, the plasma in local thermodynamical equilibrium radiates an electron cyclotron spectrum (ECS) in the range 50-500 GHz such as reported in fig.1 (solid line).

A Fabry-Perot cavity with a transmission function given in fig.1 (dashed line) can be tuned to the second harmonic of the electron cyclotron frequency of which intensity is proportional to the electron temperature Te. On TORE-SUPRA, a set of 12 Fabry-Perot cavities made with 150 l.p.i copper meshes has been developed to measure the temporal evolution of Te in a poloidal plane (fig.2).

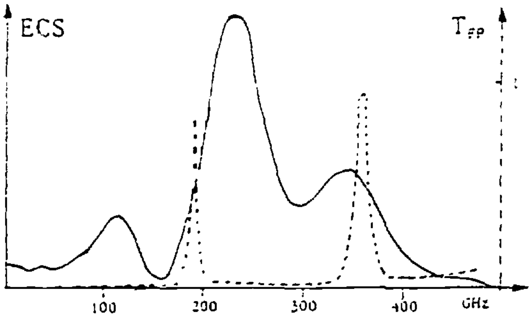

Fig.1 A TORE SUPRA Electron Cyclotron Spectrum + A Fabry-Perot transmission function (dashed line).

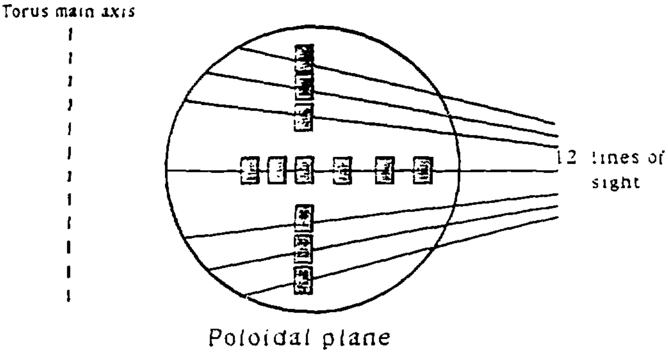

Fig.2 Fabry-Perot lines of sight on TORE SUPRA

THE FABRY-PEROT INTERFEROMETERS

Each cavity is composed of a grid mounted on a fixed support and a second one mounted on a step-by-step translation table (1 step = 2.5 µm ; Max frequency = 40 10^3 step.s^{-1}) monitored by a microcomputer. This allows to operate both in static mode with 10 GHz spectral resolution - 1 µs temporal resolution or in scanning mode to describe the 2^{nd} harmonic profile in 30 ms. In the later case, each step triggers an external clock for the data acquisition. In addition, 4 reflection gratings per line of sight are used as filters to reject higher transmission orders of the cavities.

CALIBRATION

A 800 K black-body source /1/ with 200 x 200 mm active area has been installed in the torus to calibrate the aparatus.
The most stringent difficulty to calibrate Fabry-Perot interferometers is the very low transmitted signal due to the finesse of the cavities. In comparison with a Michelson interferometer that has been calibrated in 5 hours under the same conditions, one would expect 150 hours for the Fabry-Perot because of the Michelson multiplex advantage (typically 30).
A second difficulty arises when continuous levels have to be measured. Thermal drift of the detectors and amplifiers are generaly incompatible with the calibration integration time.
We tried first a coherent addition of the spectra measured with the Fabry-Perot operating in scanning mode by analogy with the Michelson calibration. In that case, we observed an erroneous spectrum attributed to the background radiation directly coupled to the cavity. Reproducing the measurement with the black-body placed in the Fabry-Perot vicinity, we estimated the source contribution to less than 1% of the total signal. In these conditions, even substracting the spectrum obtained without the black body source, the calibration IN SITU failed.

To overcome these problems, we have developed a method summarized as follow : The Fabry-Perot cavity is used in static mode. The black-body emission is chopped at a frequency ν_c = 155 Hz. Doing that, the non-chopped signal due to the background radiation we mentioned above is eliminated. The thermal drift of the detectors and the offset of the electronics disappear using AC amplifiers. The signal to noise ratio is increased with a coherent addition of the chopped signal (the chopper delivers one synchronisation pulse every $T_c' = p\, T_c$ where p is the chopper holes number and $T_c = 1 / \nu_c$). Demodulation of the signal is performed by Fourier analysis. Then we take the amplitude of the Fourier component at the ν_c frequency (numerical filtering). ν_c must be chosen as high as possible first to increase the coherent addition efficiency and second to minimize the 1/f noise contribution in the numerical filtering.
To correctly calibrate the line, a multiplying factor has to be determined. This one results from the chopper shape (mechanical) and the Fourier transform (mathematical). It is determined measuring the ratio of the amplitude at the ν_c frequency to the incident sinusoid amplitude when one illuminates the line with a klystron or simply taking off the grids when operating with the black-body source.

SIGNAL TO NOISE COMPARISON WITH CONVENTIONAL TECHNIQUES

The following signal-to-noise ratio calculations are reported for the same integration time T .

In the case of **coherent addition** performed for example with the Fabry-Perot cavities in scanning mode, one has :

$$\frac{S}{N} \propto \sqrt{N} = \sqrt{\frac{T}{T_{sc}}}$$

where N is the total number of spectra added and T_{sc} the scanning period.

With the **coherent Fourier analysis** described therein, one can write :

$$\frac{S}{N} \propto \sqrt{\frac{Q\,T}{n\,T_c'}}$$

where n is the number of points calibrated in the spectrum (T being the total integration time necessary to obtain the calibration spectrum) and Q is a quality factor that can be estimated as follow :
The calibration signal chopped at the ν_c frequency is coherently added every $T_c' = p / \nu_c$. The resulting temporal signal is then Fourier transformed (N_{FFT} points). The sampling frequency ν_s depending on N_{FFT} has to be chosen in order to avoid spectrum aliasing :

$$\nu_s = \frac{N_{FFT}}{T_c'} = 2\,\nu_N \qquad (1)$$

where ν_N is the maximum noise frequency (imposed by an analogical conditionning).
So, the frequency resolution in the Fourier space is :

$$\delta\nu_F = \frac{\nu_s}{N_{FFT}} = \frac{2\nu_N}{N_{FFT}} \qquad (2)$$

The quality factor of the numerical filtering can be estimated by the fact that we take 1 frequency point over the broad Fourier spectrum. Let us write with (2) :

$$Q = \frac{\nu_S}{\delta\nu_F} = N_{FFT} \quad ; (\sqrt{Q} \text{ for amplitudes ratio }).$$

It is important to notice that N_{FFT} cannot be adjusted as wanted to increase the signal to noise ratio. Q is determined by the choice of ν_N , see (1) . It explains only the dynamical advantage of the numerical filtering for a given noise band.

Lock-in-amplifiers in **synchronous detection** are also often used to increase the signal to noise ratio. The gain is however limited to 60-80 dB by their restricted dynamical range /2/. In another point of vue, these amplifiers introduce electronical or manual (phase switch) uncertainties that do not appear in the numerical lock-in described precedently.

RESULTS

Taking typically n = 100 points to scan the spectrum between 150 and 300 GHz and N_{FFT} = 512 points, the signal to noise ratio is $\sqrt{5}$ times better than the one obtained with the coherent addition method. In other words, the duration expected to calibrate one line is 5 times less (i.e 30 h).

The calibration curve obtained in these conditions is shown in fig.3 . Te measurement for shot 3004 is reported in fig.4 (solid line) with a comparison with the Thomson scattering measurement (dots).

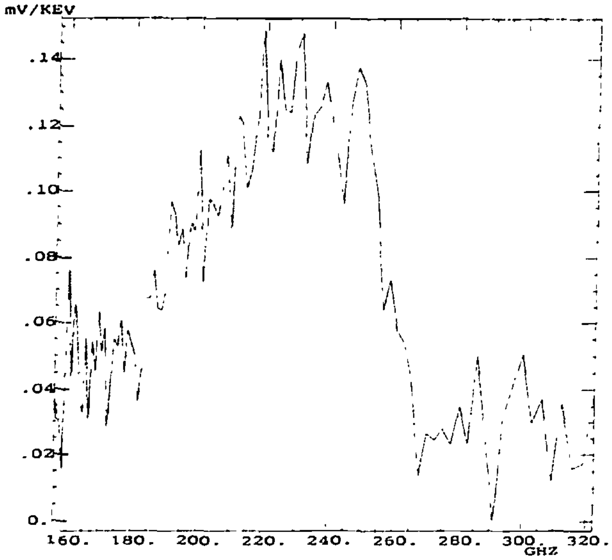

Fig.3 Calibration curve .

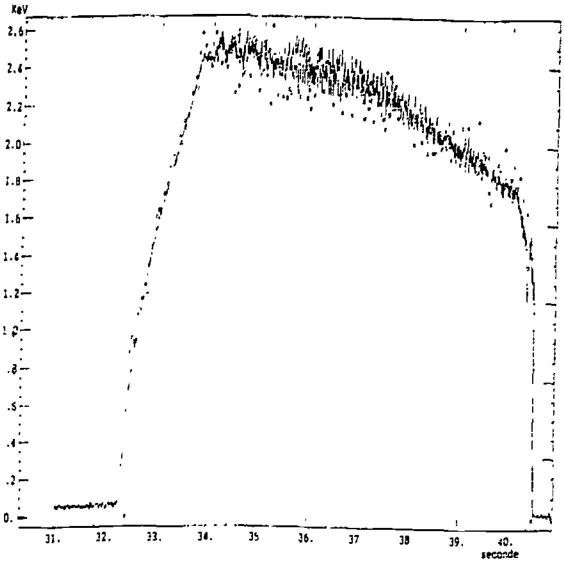

Fig.4 Absolute Te measurement with a Fabry-Perot interferometer .

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