# 7. PARTICIPATION IN THE TCV PROGRAMME

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## 7.1. INTRODUCTION

The participation of the Association EURATOM/IST in the TCV programme has been focussed on the development of three X-ray diagnostics:

- An horizontal Pulse Height Analysis (PHA) diagnostic;
- A vertical PHA diagnostic;
- A rotating crystal spectrometer.

The following main activities were performed:

- Improvements on the operation of the horizontal PHA spectrometer;
- Design of the vertical PHA spectrometer and ordering of the detector and a CAMAC module for signal conditioning and data acquisition;
- Finalization of the design of the X-ray rotating crystal spectrometer based on hardware lent by Princeton Plasma Physics Laboratory (PPPL);
- Continuation of the laboratorial tests of the PPPL hardware;
- Purchase of a new high-voltage power supply and a step motor;
- Design of new electronic units;
- Realization of a one-day meeting at CRPP for evaluation of the results of this collaboration and definition of the 2002 work programme.

## 7.2. PULSE HEIGHT ANALYSIS DIAGNOSTICS

### 7.2.1. Introduction

Two Pulse Height Analysis (PHA) diagnostics of the soft X-ray plasma radiation are planned for TCV, for the measurement of the electron temperature in the plasma core and to survey the plasma impurity content.

The first spectrometer, in operation since 1997, is installed along one horizontal line of sight deviated 13.5$^o$ from the tokamak major radius and that crosses the port geometrical centre. It is based on a Germanium detector and a home-made Interface Amplifier and Time Generator unit, being the pulse height analysis made by software from the data acquired by a VME transient recorder module.

A new spectrometer has been designed aiming at enhancing the precision of the measurements by improving the sensitivity, the statistics and the resolution of the diagnostic. To accomplish these requirements a system with high throughput is needed. This spectrometer is based on a SDD with a Peltier cooling system and a CAMAC module that digitises the pulses provided directly by the preamplifier and gives a set of spectra at its output. The diagnostic will be installed in a vertical port allowing the analysis of almost all the TCV plasmas.

### 7.2.2. Experimental results

The electron temperature ($T_e$) can be calculated from the experimental data provided by a PHA diagnostic, assuming that the electron distribution function is Maxwellian. In this case, the energy radiated $I(\varepsilon)$ by a number of electrons $g(\varepsilon)d\varepsilon_e$, contained in one cubic meter of plasma, with kinetic energy between $(\varepsilon_e, \varepsilon_e + d\varepsilon_e)$ moving through an ion cloud of density $n_i$, is given by

$$I(\varepsilon) = 9.40\times10^{-20} Z^2 n_i \int_{\varepsilon}^{\infty} \frac{g(\varepsilon_e)}{\sqrt{\varepsilon_e}} d\varepsilon_e \qquad (7.1)$$

Assuming that $g(\varepsilon)$ is written as a sum of distribution functions, the resulting spectrum is the sum of the corresponding spectra. The distribution function can be reconstructed by differentiating the spectrum with respect to ε,

$$\frac{dI}{d\varepsilon}(\varepsilon) = -9.40\times10^{-20} Z^2 n_i \frac{g(\varepsilon)}{\sqrt{\varepsilon}} \qquad (7.2)$$

This expression seems to be rather complicated but, the important fact here is that it is proportional to $\exp(-\varepsilon/T_e)$. For the Maxwellian distribution,

$$g(\varepsilon) = \sqrt{\frac{4}{\pi}} \frac{n_e \sqrt{\varepsilon}}{T_e^{3/2}} \exp(-\varepsilon/T_e) \qquad (7.3)$$

and the Bremsstrahlung spectrum takes the form,

$$I(\varepsilon) = 9.40 \times 10^{-20} Z^2 \frac{n_i n_e}{\sqrt{T_e}} \exp(-\varepsilon / T_e) \qquad (7.4)$$

The electron temperature in the plasma core can be calculated from the slope of the bremsstrahlung and recombination radiation spectrum on a semi-logarithmic graph, without any need for an absolute calibration[1].

A Matlab routine was written to calculate the electron temperature. It starts to convert each channel number into the correspondent energy using the calibration line and performs corrections for the detector's efficiency, i.e, it corrects the counts in each channel with the transmission factor of the detector's beryllium window. The data logarithmisation is the last command performed before the spectra being printed.

Figure 7.1 shows results obtained with the horizontal PHA diagnostic: the raw data histogram, the data histogram with correction for the filter absorption factor and the reduced residuals used for evaluation of the fit quality.

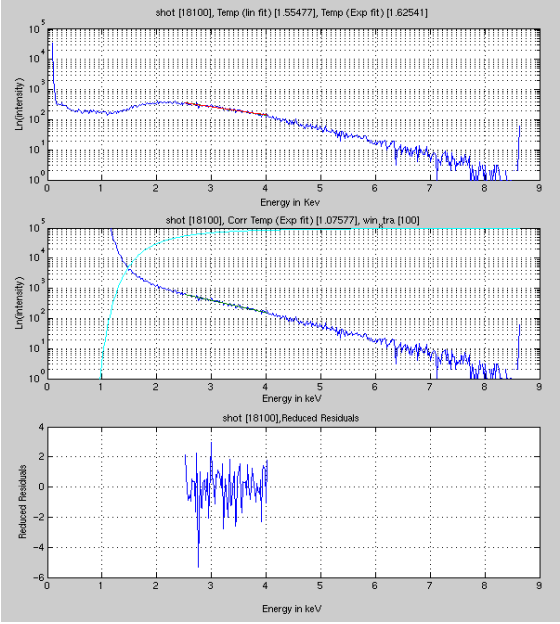



*Figure 7.1 – Raw data histogram (A), data histogram for correction for the filter absorption factor (B) and reduced residuals for evaluation of the fit quality*

[1] From the previous expressions we see that the slope of the *Bremstrahlung* should be negative and equal to $1/T_e$ .

Figure 7.2 compares the values of the electron temperature measured with the horizontal PHA and the Thomson scattering diagnostic.

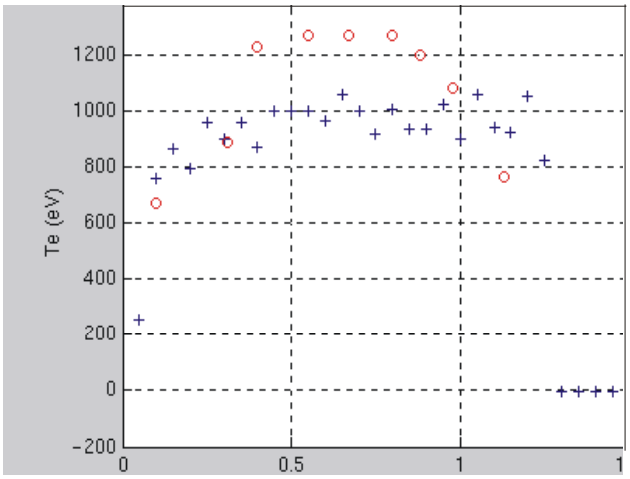



*Figure 7.2 - Comparison of the values of the electron temperature obtained with the Thomson Scattering (+) and the PHA (o) diagnostics.*

## 7.3. ROTATING CRYSTAL SPECTROMETER

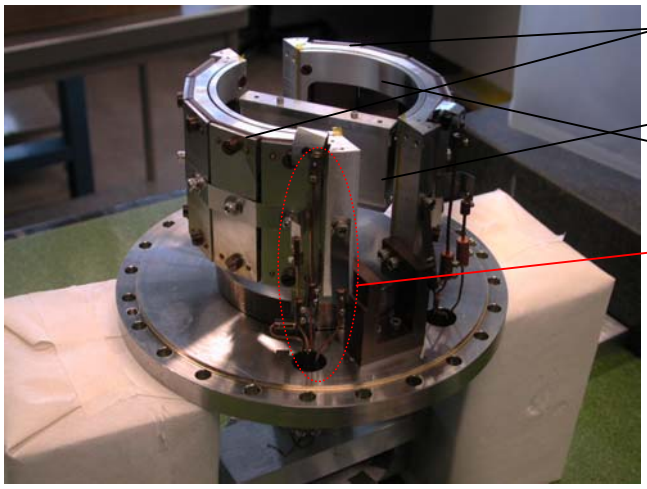
The operation of the rotating crystal spectrometer is based on Bragg's Law:

$$n\lambda = 2d \sin\theta \qquad (7.5)$$

where λ is the wavelength of the illuminating radiation, θ is the angle made by the radiation path to the crystal and the crystal face, d is the distance between atomic planes in the crystal and n is the order of reflection. A photon that is not in a narrow energy band of satisfying Bragg's Law is not reflected, so the device acts as a spectrometer passing only a particular wavelength and its higher orders. The crystal can be either set at a particular angle, in which case the output signal represents the time history of the line emission, or it may be rotated so that different angles are continuously sampled and the radiation selected sweeps an entire spectral range.

Figures 7.3 and 7.4 present a photo and drawings of the main components of this spectrometer as well as a block diagram of the diagnostic.

A TAP crystal (thallium hydrogen phthalate, $TlOO.C_6H_4.COOH$, 2d=25.67Å) and a AdP crystal



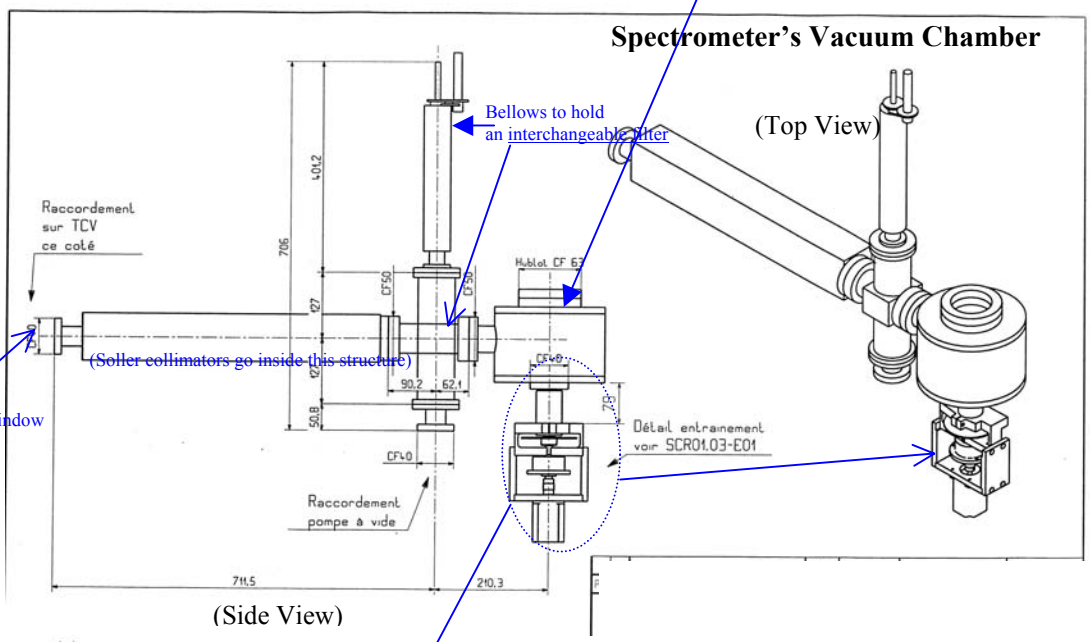
two sets of
Microchannel Plates

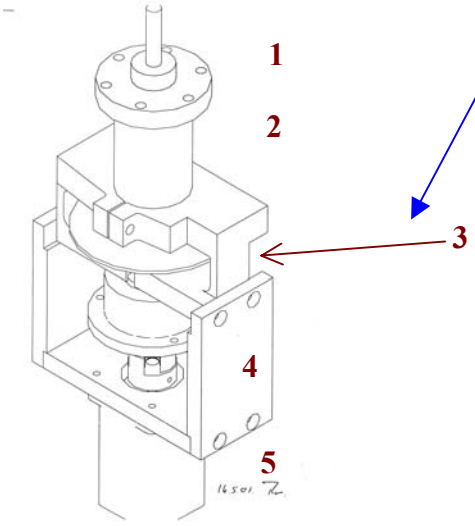
crystals

Foil holder

Electrical connections of the Microchannel plates to the amplifiers and the High Voltage Power Supply

The MCP and the crystal are enclosed inside the cylindrical body of the vacuum chamber.




Drawing of the mechanical structure, placed under the MCPs, that holds the crystal turning mechanism and encoder system:

1- Shaft
2- Vacuum Holder
3- Slotted Disk
4- Angle Encoder
5- Step Motor

*Fig. 7.3 – Photo and drawings of the main components of the rotating crystal spectrometer*

(ammonium-dihydrogen-phosphate, $NH_4H_2PO_4$, 2d =10.618Å) were mounted on each side of an aluminum holder which is attached to a rotating vacuum feedthrough. The feedthrough is attached to a slotted disk, which used to be attached to some probe drive, which was no longer there. A light emitting diode should straddle the slotted disk and produce a signal pulse on a phototransistor whenever a slot is encountered. A printed circuit was conceived to read and convert the signals coming from the emitting diode. The reflected radiation is detected by two ensembles of four pairs of Micro Channel Plates in a rough circle around the crystals. Each Microchannel Plate consists of about $10^7$ miniature channel multipliers at 8º to the normal and two plates are sandwiched with their angles opposite into a chevron configuration, to reduce spontaneous cascading. There follows a collector plate to receive the electrons. When a voltage is applied and a photon strikes the detector an electron current is produced. The resulting signal current is usually tens of microamps and must be amplified to some volts. A transimpedance amplifier is usually employed. To make the crystal turn it is used a programmable stepper motor. Also, a unit called router/mixer, which will be the interface between the TCV acquisition system and the step motor controller, was manufactured in a way that the whole structure can be remotely conducted. The transient recorder digitises the signals coming from the router/mixer and sends them to the TCV data base, to be stored.

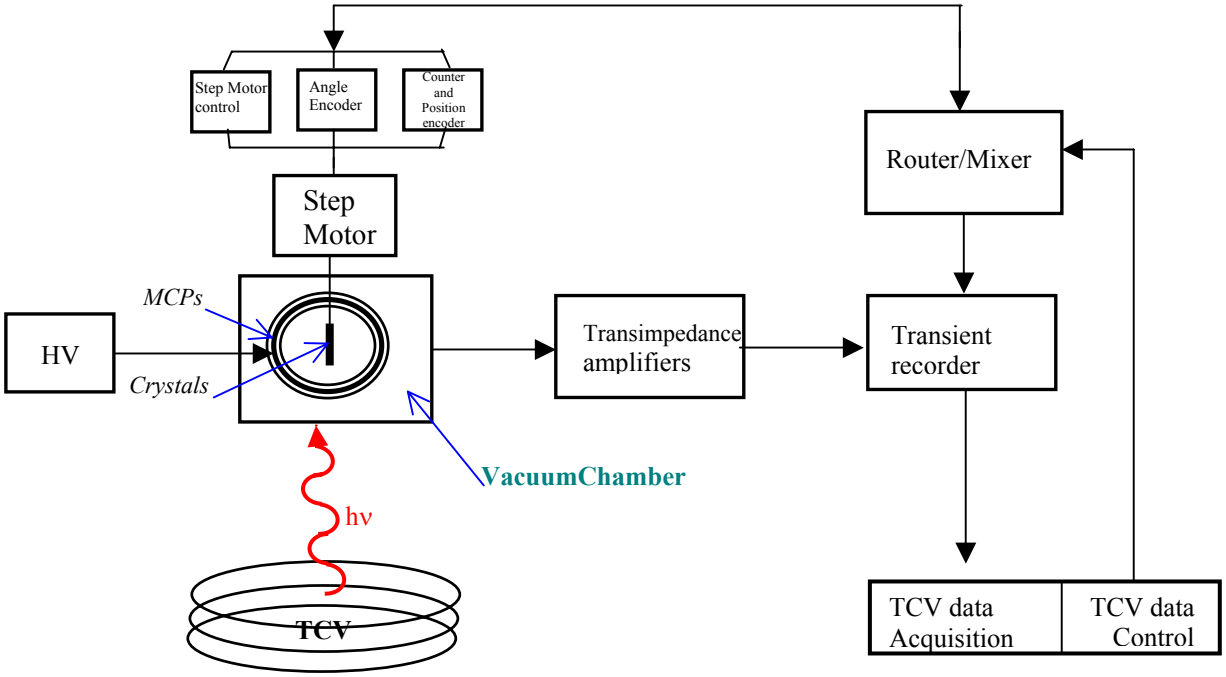



*Fig. 7.4 – Block diagram of the rotating crystal spectrometer*