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# Feedback Estimation for Magneto Hydro Dynamics Instability Controller

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## *Abstract*

In this paper a Bayesian theory based method is presented to estimate how much Electron Cyclotron Heating (ECH) power is deposited accurately on the expected deposition area inside Tokamak. The deposition area is attributed by a minor radius (rDEP) and this paper introduces an innovative method for its estimation. It is done by processing the measurement signals that are gathered from Electron Cyclotron Emission (ECE) channels. The method observes the data from ECE channels for determining the amount of ECH power deposition on the expected deposition area in plasma. To show the efficiency of the method, it has been tested on a sample off-line ECE channels data that has been acquired from the experimental shots at FTU in Frascati, Italy.

***Keywords:** Estimation; Bayesian Filter; Plasma Control; Data Fusion; Tokamak.*

## 1. Introduction

A Tokamak is a machine producing toroidal magnetic fields to confine the plasma and it is designed for achieving the controlled thermonuclear fusion power. Density limit disruptions are connected with the evolution of Magneto Hydro Dynamics (MHD) instabilities associated to magnetic islands. Active control of MHD instabilities is important in order to improve tokamak performance [1]. Localized heating by Electron Cyclotron Heating (ECH) systems is a promising tool for active control of the MHD [2]. The ECH heating system, composed of some high power ECH line sources that can be steered independently, must be controlled in order to deposit the heating power in a plasma layer as close as possible to the magnetic island position [3], [4]. Controlling MHD instabilities includes two parts: 1) detection of deposition channel, 2) detection of target channels. In the proposed algorithm in this paper we use the ECE channels data, ECH power data and the prior information. Prior information is the deposition minor radius that we got from the controller which we want to send the ECH power to that surface and heat the magnetic island. In practice the prior information varies according to the time, but in our simulation for simplicity we assumed that the prior information is a constant value and this would be east to generalize it to the varying case. The proposed algorithm for estimating the deposition minor radius ($r_{DEP}$) supervises the ECE channels data continuously to determine if electron cyclotron heating (ECH) power is correctly deposited on the expected radius of the rotating plasma in the Frascati Tokamak Upgrade (FTU). The overall structure of the algorithm is demonstrated in figure 1.

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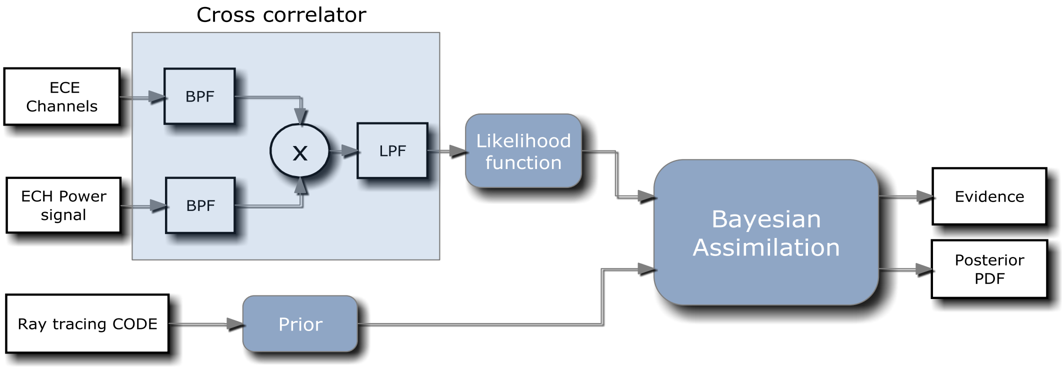

**Figure1.** The overall structure of the diagnosis algorithm

## 2. Data Pre-Processing

Frascati Tokamak Upgrade (FTU), a compact high magnetic field tokamak, started in 1990 operating from the beginning with all the raw and elaborated data archived using two standard header channel descriptions [5]. So the FTU users have been always able to access data coming from all diagnostics ignoring any details about the hardware setting; a unique library call with the two keys, shot number and channel name, let the user get all the different data. FTU has reached the complete working configuration with three auxiliary heating systems to investigate radio frequency power deposition [6]. We used Shot Number 21364 in the FTU tokamak to test the algorithm. The ECE temperature fluctuations on all channels (ECE channels data) vs. time are depicted in figure 2. It shows the original 12 ECE channels data. ECE channels number 5, 6, 7 are the hottest area of the plasma which means they measure the temperature of the plasma center [7].

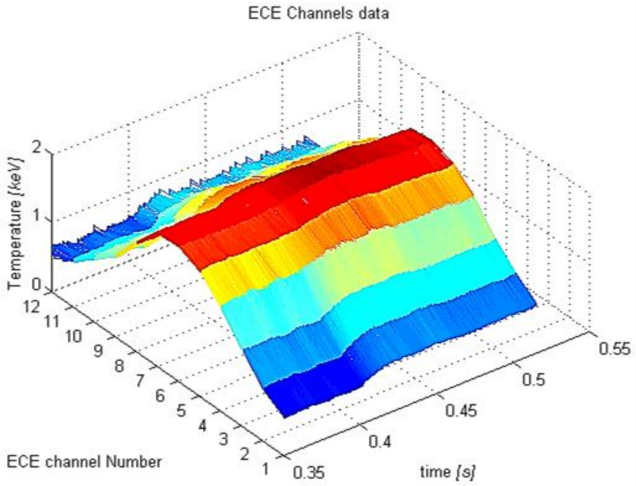

**Figure2.** ECE temperature fluctuations on all channels vs. time in FTU Tokamak (Shot # 21364)

In order to avoid oscillation while filtering the channels a ramp is added to the beginning point. Furthermore 12 channels are interpolated to 23 channels for better resolution for the following process as shown in figure 3.

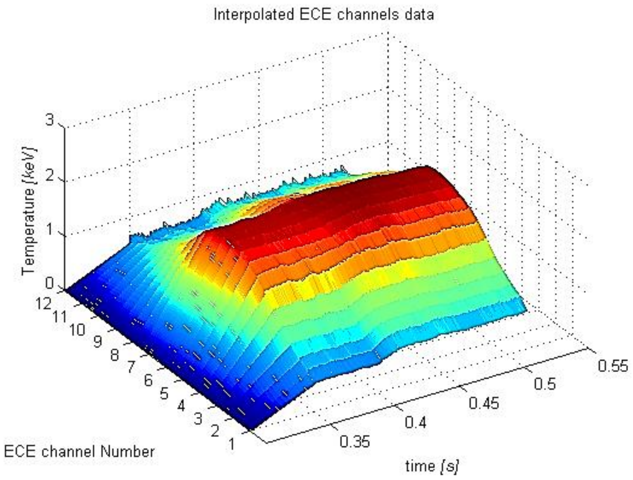

**Figure 3.** Interpolated and ramp added to temperature profile in FTU Tokamak (Shot # 21364)

Measurements of the spectrum of electron cyclotron emission (ECE) are now used routinely to obtain the electron temperature with good spatial and temporal resolution. An ECE diagnostic is planned for measurement of the electron temperature in a tokamak. A temperature fluctuation study is needed during auxiliary heating to investigate magneto hydro dynamics (MHD) activities before and during disruption, which requires high temporal resolution (10µS). The above demands can easily be met by ECE diagnostics in comparison with other conventional methods such as *Thomson scattering* and *soft X-ray* measurements [8].

In a typical experiment, noise can arise from a variety of sources. For example, it may not be possible to subtract out entirely the radiation associated with the background plasma, especially in the vicinity of the cyclotron harmonics. A second source of noise arises from our inability to calibrate precisely a large array of radiation detectors. Moreover, there may be unwanted reflections within the plasma chamber that interfere with the direct radiation signal. It is not our intention to construct precise models for these sources of noise ; rather it is our intention to propose a generic model for noise and other unwanted effects, and then to examine how robust our algorithm remains in the presence of possibly large amounts of this generic noise. It is our expectation that this robustness will not be particularly sensitive to our choice of noise model.

The noise model that we employ assumes that each attempt to measure experimentally $R_x(\omega,\tau)$ results in pollution by an extraneous signal $\tilde{R}(\omega,\tau)$ which $R_x(\omega,\tau)$ is the radiation emitted at frequency $\omega$ and time $\tau$ . Thus, we measure only

$$R_x(\omega,\tau)+\tilde{R}(\omega,\tau)$$

We make further assumption that the noise $\tilde{R}(\omega,\tau)$ is Gaussian and uncorrelated over the discrete measurements that we make; each measurement of the pattern $R_x(\omega,\tau)$ is corrupted by a noise $\tilde{R}$ , with the properties $<\tilde{R}>=0$ and $<\tilde{R}^2>=\sigma^2$ [9].

## 3. Bayesian Estimation

To understand the role of uncertainty estimation in the proposed algorithm it is important to consider two types of information for estimating the deposition radius ($r_{DEP}$) for each ECH heating line: 1) to measure it directly using different diagnostic instruments (radiometers, Mirnov coils, soft X-ray emission) and 2) to predict it indirectly by ray tracing of the ECH line paths (predicting $r_{DEP}$) given the steering angles of the ECH antennas. The two possible approaches, i.e. direct measurement or prediction using complex mathematical models, have opposite characteristics in terms of sensitivity and uncertainty. In fact the uncertainty of the model predictions are quite high while the sensitivity is in principle infinite, since the models can predict the position of the ECH deposition layer even when there is no magnetic island in the plasma and with heating system turned and no power deposition.

The direct measurements are characterized instead by a lower uncertainty but with finite sensitivity due mainly to plasma noise: to be detected a magnetic island needs to have a size wider than a threshold level defined by the sensitivity of the measurement. The deposition of the ECH lines can be measured only if the ECH system is turned on and the adsorbed heating power produces a detectable localized plasma temperature change.

Because of the opposite characteristics of the two above mentioned approaches to the position estimation of $r_{DEP}$ we have proposed to use a combination of both using the principle scheme shown in figures 1.

Both the estimators use a Bayesian filter to assimilate together the available estimates. The assimilation principle is implemented by the Bayesian filter as given by the Bayes law:

$$p(r_{DEP} \mid d) = \frac{f(d \mid r_{DEP}).p_{q=2}(r_{DEP})}{p(d)} \propto f(d \mid r_{DEP}).p_{q=2}(r_{DEP})$$

$$p(d) = \int_{IR} f(d \mid r_{DEP}).\,p_{q=2}(r_{DEP}).dr_{DEP}$$

The probability density $f(d \mid r_{DEP})$ represents the probability density function (PDF) of the estimate of $r_{DEP}$ obtained using the available instruments only when $d$ is the measurement data vector, while $p_{q=2}(r_{DEP})$ is the estimate obtained using the mathematical model (a-priori PDF). Finally $p(r_{DEP} \mid d)$ is the result of the assimilation of two estimates (a-posteriori PDF). The number *p(d)* represents the evidence of the data *d*.

## 4. Simulation

The Bayesian theory based estimation algorithm is applied to the FTU shot number 21364 during the simulation time from 0.4S to 0.52S. The original and interpolated 12 ECE signals have been shown in figure 2 and figure 3 respectively. The original ECE channels data and ECH power A for shot number 21364 obtained from FTU off-line database is given as the input to the algorithm.

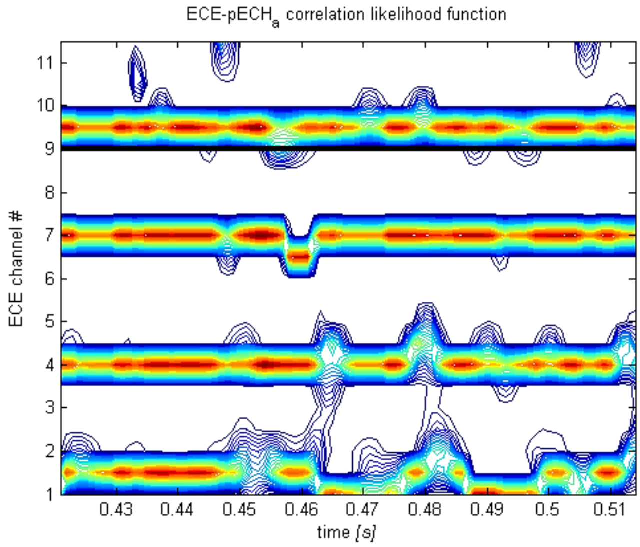

**Figure 4.** ECE and ECH power *A* cross-correlation likelihood PDF for ECH power A

The ECE and ECH power *A* cross-correlation likelihood PDF for ECH power A is plotted in figure 4. Figure 5 shows the contour plot of the fused likelihood and prior information which is resulted as posterior PDF. The thick black line represents the prior mean (that is located on channel 9) in both of the figures.

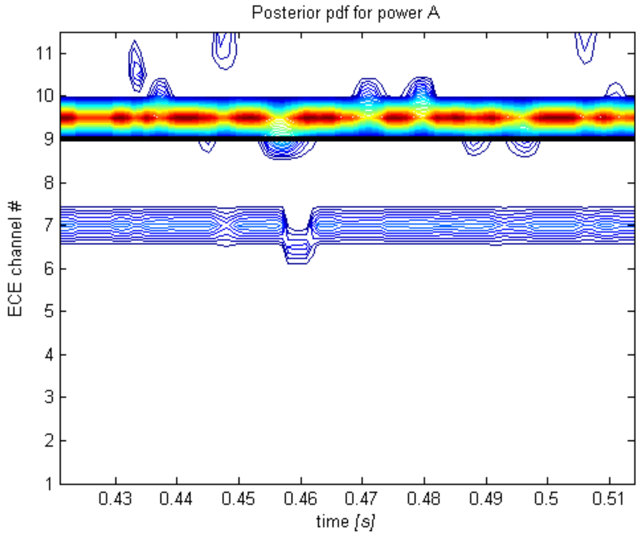

**Figure 5.** Posterior PDF for ECH power A (no noise)

Mean and standard deviation (upper and lower uncertainty bound) of the deposition channel resulted from the posterior PDF for ECH power *A* is depicted in figure 6. *Linear opinion pool* method is used for computation of the mean and uncertainty.

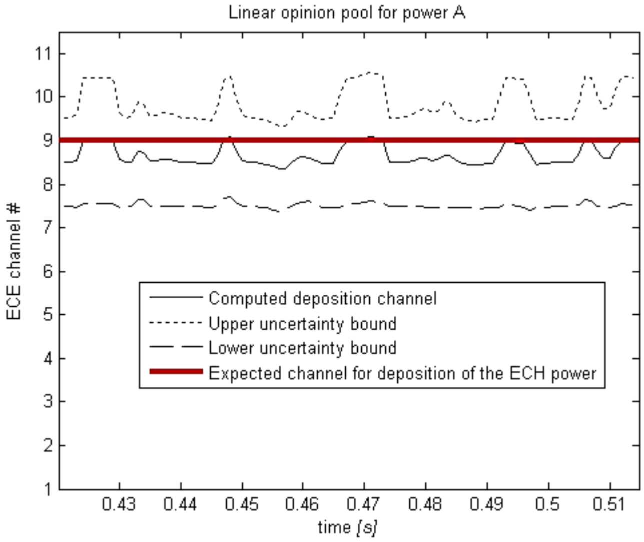

**Figure 6.** Upper and lower bounds of the deposition channel (no noise)

The black solid line show the computed deposition channel (mean values), red thick line shows expected channel for deposition of the ECH power (prior information), dotted and dashed lines show the upper and the lower uncertainty bounds. Figure 7 shows the posterior PDF for ECH power A when the signal noise ratio (SNR) is 50dB. Upper and lower uncertainty bound of the deposition channel resulted from the posterior PDF in presence of noise is depicted in figure 8.

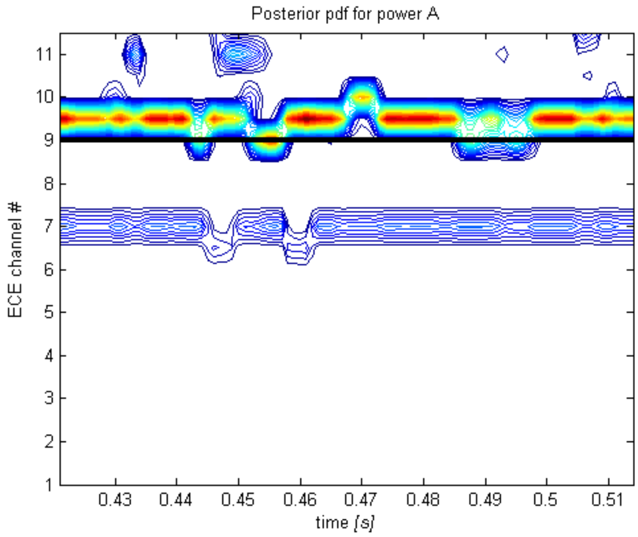

**Figure 7.** Posterior PDF for ECH power A (SNR=50dB)

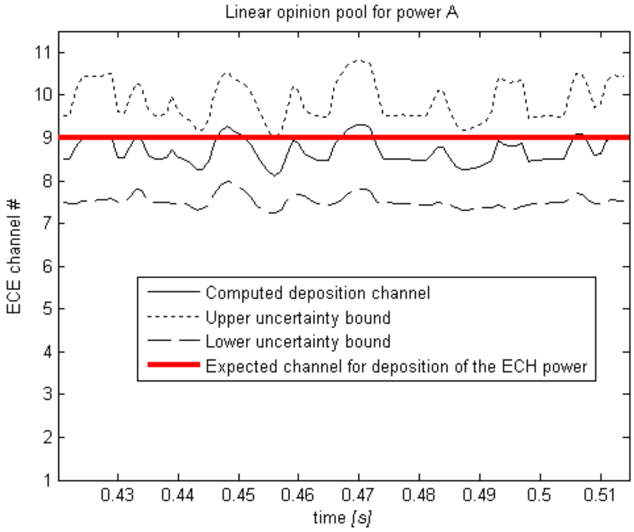

**Figure 8.** Upper and lower bounds of the deposition channel (SNR=50dB)

Comparing the upper and lower bounds of the deposition channel in the figure 6 (case1: no additive noise) and 8 (case2: with additive noise), it can be seen that the uncertainty bounds has become broader and this algorithm estimates the deposition channel correctly even with the additive noise. The estimation of the deposition channel using this algorithm is still acceptable.

## Conclusions

This paper presented a Bayesian theory based method to estimate the amount of Electron Cyclotron Heating (ECH) power deposition in the Tokamak. This paper introduced an innovative method for estimation of the deposition location that is done by pre-processing the Electron Cyclotron Emission (ECE) channels measurement signals for determining the amount of ECH power deposition on the expected deposition area in plasma. The method has been applied to the off-line data (shot number 21364) that has been acquired from a sample experiment in the FTU in Frascati, Italy and the simulation results show that the proposed method has successfully determined the accurate deposition channel. The method has shown its efficiency even when the data has exposed with additive noise up to the level SNR=25dB and the estimation of the deposition channel using this algorithm is still acceptable. For the future work, it will be valuable to extend and test the algorithm for higher levels of noise.

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