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Real time magnetic flux surface positions for ASDEX Upgrade

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Introduction

The need for locating the q = 2 or q = 3/2 rational magnetic flux surface position in real time for NTM stabilisation experiments in ASDEX Upgrade [1] has driven the development of a dedicated data acquisition system to achieve this goal. Measurements of integrated magnetic field from magnetic probes and flux loops and measurements of the currents flowing in the poloidal and toroidal field coils of ASDEX Upgrade make up the set of 100 measurements used with the CLISTE tokamak equilibrium code. This code reconstructs the magnetic flux surfaces in ASDEX Upgrade [2] and cannot be presently carried out in real time. For the real time control system, a function parameterisation algorithm is used to calculate the magnetic equilibrium [3]. This statistical analysis of randomly chosen equilibrium states generates 2 sets of matrix coefficients. The calculation of 95 equilibrium parameters and the magnetic flux surfaces on a 39x69 grid is reduced to the product of these matrices and a vector of 153 elements consisting of a second degree polynomial in the leading 16 principal components of a vector of 58 measurements. For NTM stabilisation, the mirror is steered to the position required to deposit ECCD power on the rational flux surface. This position will be calculated in real time by the control system from the spatial co-ordinates of the relevant rational magnetic flux surface provided by this dedicated data acquisition system [4]. A schematic diagram of these features is shown in Fig. 1.

Data acquisition

The data acquisition system consists of 128 analog inputs recorded by 16 National Instruments PXI 6143 S Series cards with 16 bit ADC's and sampling rates up to 250 kHz . All channels will be acquired simultaneously (at 10 kHz initially) for the duration of the discharge. A Dell PowerEdge 2950 with two quad core Intel Xeon X5355 2.66 GHz processors, 16 GB memory and Windows Server x64 2003 are connected to the data acquisition cards in a 18 slot PXI chassis via a PCIe-PXI bridge. As this bridge can transfer data at rates up to 110 MB/s from one chassis, a sampling rate up to the maximum 250 kHz with all 128 channels is possible. Tests with real time communication to the control system on an operating system not normally used for real time applications are planned.

The original LabVIEW 8.2 application was optimised to make maximum use of the parallel processing available [5]. A computation time of less than 0.6 ms could be achieved for the matrix multiplications and contouring needed to calculate the magnetic flux surfaces. The execution time of the matrix operations was shown to decrease from 0.80 ms to 0.35 ms when increasing the number of processors used from 1 to 8 for the test case with 16 principal components [5]. The evaluation of the 95 equilibrium parameters could be carried out at the sampling rate of 10 kHz. Suitable control system outputs are to be produced by filtering the input data to these algorithms with a fourth or sixth order Bessel filter at half the frequency of the control system cycle at ASDEX Upgrade (300 Hz to 500 Hz). Eventually MSE data will be received in real time for refining the real time magnetic equilibrium calculations. This will increase the number of matrix operations by 50%, as 20 principal components instead of 16 are then needed. Despite this increase, a computation time comparable to the 1 ms cycle time planned for the central control system will be achieved.

Application

In the absence of plasma, the predicted magnetic probe and flux loop measurements can be calculated. For these calculations, the ASDEX Upgrade coil system is modelled by a set of individual current loops located at a given vertical position and radius. These calculations simply sum the magnetic field and poloidal flux, ψ, due to an axisymmetric current loop [6] over each of the individual coils at the given positions of the magnetic probe or the given radius and vertical position of the flux loop. This application has been tested with recorded data for the test shots with an individual current in each of the poloidal field coils and runs with a computation time of 13 microseconds. It is planned that this application assists in monitoring these measurements in real time for possible magnetic probe or flux loop failure during a discharge.

The spatial co-ordinates of the m/n = 3/2 or 2/1 rational magnetic flux surface are needed for positioning the ECCD mirror in NTM stabilisation experiments. This information is valuable even prior to the growth of an NTM as this allows the mirror to be positioned ready for ECCD power deposition with minimal delay when required. In addition, flux surfaces near the separatrix are required to estimate the extent to which an electron density gradient deflects the microwave beam. The X-Y co-ordinate array for a given ψ equals constant value defines the magnetic flux surface. This array will be sent to a central real time signal processor that combines the signals from the various diagnostics involved in the NTM stabilisation experiments. In Figure 2, a contour plot of normalised ψ from shot 20826 at t = 4.8 s as calculated by the real time LabVIEW application is shown.

Future real time applications

The Grad-Shafranov equation is the partial differential equation used to calculate the magnetic equilibrium in a tokamak [7]. The magnetic flux surfaces are calculated after a discharge and are typically on a finer 64x128 grid. The solution of the Grad-Shafranov equation represents the magnetic equilibrium with the best fit to the experimental data and is more accurate than the functional parameterisation solution as it avoids the compromises involved in using a finite number of principal components. Our final aim is that solutions to the Grad-Shafranov equation could be carried out in real time with the refinement of algorithms employing matrix operations to solve partial differential equations in a multiprocessor environment [5]. The magnetic flux surfaces in ASDEX Upgrade could then be communicated more exactly to the real time control system. Similarly, the matrix operations required for the tomographic inversion of line integrated bolometer measurements could be another candidate for utilising the multi-core architecture for real time evaluation. Presently, the total radiated power in the main chamber and divertor are calculated from a weighted linear combination of the line integrated power fluxes of appropriate lines of sight. A real time tomographic inversion would provide a more accurate estimate of these values as the statistical nature of the weighting coefficients could be avoided. It is proposed that a cluster of 10 blade servers, with dual 8 core processors in each server, would be an interesting platform to realise such ambitions.

Conclusions

The calculation of magnetic flux surfaces with a computation time of less than 1 millisecond has been prepared for NTM stabilisation experiments on ASDEX Upgrade. The calculation of magnetic probe and flux loop response to the currents in the poloidal field coils of ASDEX Upgrade with a computation time of less than 15 microseconds will assist in monitoring these signals in real time. Both these applications achieve the desired performance by utilising the parallelisation offered by the LabVIEW software development environment on a multiprocessor platform using eight cores.

References

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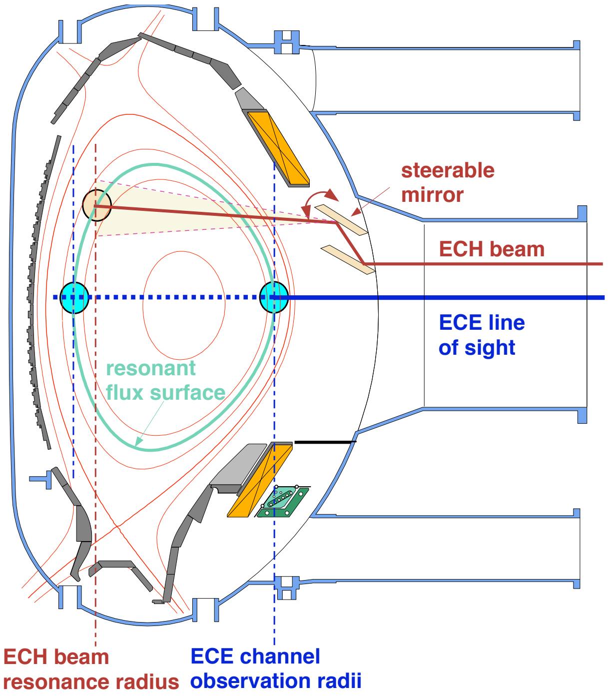

Figure 1: *Schematic diagram of NTM stabilisation on ASDEX Upgrade*

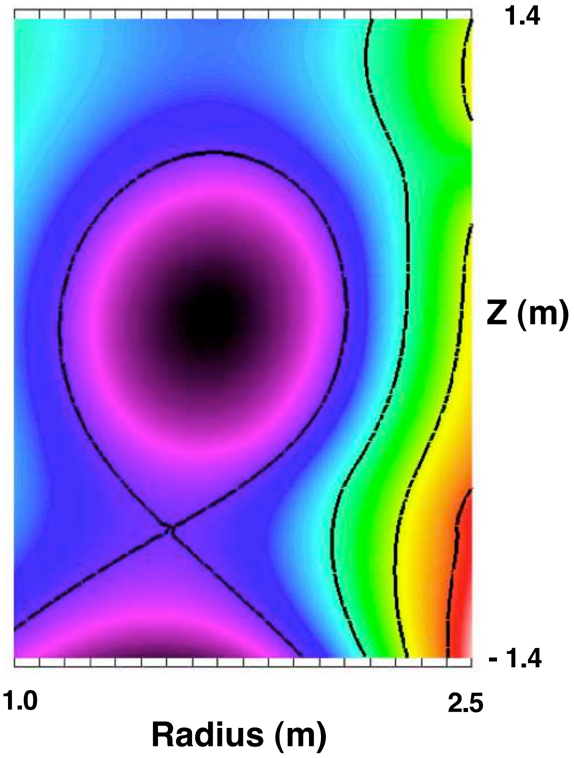

Figure 2: *Contour plot of normalised* ψ *with contour lines at* $\psi = 1, 2, 3$ *and 4. The magnetic flux surfaces are constants in* ψ *and the separatrix is located at* $\psi = 1$.