Expansion of ASDEX Upgrade's real-time parameter recovery routine to include additional moments in the current profile

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Introduction

Function parameterization (FP) [1][2] is the method of choice for real-time recovery of plasma parameters in the ASDEX Upgrade experiment. Presently, the FP routine uses a subset of high variance linearly independent combinations of the external magnetic measurements to predict a wide variety of plasma parameters.Due to the lack of internal measurements FP cannot identify the details of the current profile or of other internal plasma parameters.

Improved Predictor Generation for FP

The present FP model is based on a database with 9000(approx) plasma equilibrium states simulated over an experimentally relevant parameter subspace. From these equilbria simulated measurements and predictors are produced. There are 58 magnetic measurements (18 flux difference and 40 magnetic probes) used in the model. These 58 highly correlated measurements are dimensionally reduced by the method of principal component analysis (PCA) [3] to create 16 PC predictors. These PCs are orthogonal linear combinations of the measurements($X_{i,r}$) , created by diagonalising the correlation matrix of measurements and chosing the eigenvectors with highest variance as the measurements weights $\omega_{s,k}$. A quadratic regression of the recovered parameters $p_{i,l}$ (to be recovered) against the predictors (which is linear w.r.t. the regression coefficients) is then carried out to calculate the regression (FP) coefficients $\beta_{k,j,l}$.

This FP model (FPG) concentrates on the recovery of geometric plasma parameters. It lacks the information to recover with much detail any internal parameters. To include MSE [4],data so an FP model (FPJ) could better recover internal parameter, would involve increasing the number of PCs in the present model. Since the FP model scales quadratically with the number of PC's, this would lead to a significantly larger model size for the real-time parameter recovery algorithm. Due to computational restrictions this could cause the real-time recovery of internal parameters to become non-viable. However, since the PC method does not consider the relationships between the measurements and the plasma parameters, it cannot be the optimal method of dimension reduction.

Presently a new method of predictor generation is being studied. This method uses both the 58 magnetic measurements and 10 MSE measurements. Each set of measurements are dimensionally reducted by PCA to rid the FP model of noise and redundancy due to measurement correlation. This reduced number of 'transformed' measurements $X_{i,r}$, analgous to the 'raw' measurements in the PC model,are used in a nonlinear optimisation predictor generation routine (NLO). The difference is that the NLO routine optimises both the measurements weights and the FP coefficients. It is hoped that this routine will allow a reduced number of predictors in the FPJ model so it will be computationally viable to recover details of the current density profile. The model is shown below to best illustrate the FP (NLO and PC) model. Both models are identical in structure , but ,as already stated the NLO procedure varies the measurements weights to further optimises the predictors while in the PC model they are the eigenvectors obtained from the PCA.

$$p_{i,l} = \sum_{k=0,\, j=k}^{NLC} \beta_{k,j,l}(\sum_{s=1}^{NME} \omega_{s,k}.(X_{i,s}))(\sum_{r=1}^{NME} \omega_{r,k}.(X_{i,r})) + \epsilon_{i,l}$$

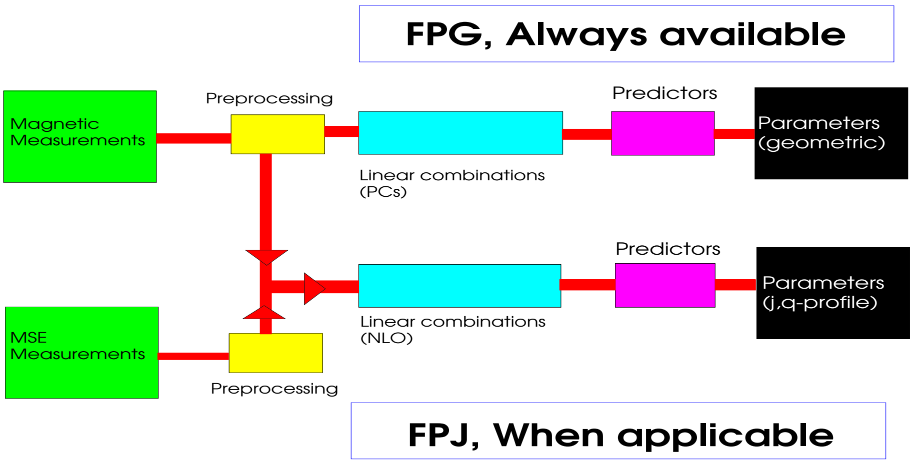
$p_{i,l}$ Recovered Plasma Parameter, $\beta_{k,j,l}$ FP Coefficient, $\omega_{s,k}$ Measurement Weight, $X_{i,r}$ (Transformed) Measurement.

FP Recovery of Internal Plasma Parameters (FPJ)

The present real-time recovery program concentrates on recovering the geometry of the outer flux surface, the zeroth moment of the pressure profile W_p, and the zeroth and first moments of the current profiles I_p and li.

Motional Stark effect (MSE) diagnostic [4] data is being added to the present measurements to recover j_ρ,q-profiles which will be used in the real-time feedback control of the current profile shape using the newly aligned tangential neutral beam sources on ASDEX Upgrade [5]. Presently it is estimated that 16-20 predictors will be necessary to accurately recover these profiles. These predictors will be derived from the 58 magnetic measurements plus the 10 MSE measurements. In the future it is hoped to add further 10 MSE channels to obtain information on the radial electric field profile.

Schematic of the realtime FP process



FPJ will run in parallel with FPG, FPG will continue to recover the geometric parameter while FPJ will recover the internal parameters. This structure is necessary because FPJ is only available when MSE measurements are being taken,while FPG is used through out the whole shot.

Initial Results

These inital results are based on calculations done on a geometrically restricted database. The database contained 1347 observations which were generated so to keep the separatrix in a quasi-static spatial position by fixing the lower X-point position and allowing only a small variation ($\leq$5cm) in R_{inner} and R_{outer}. After the measurements were generated noise was added to simulate realistic measurements (1mT in the magnetic and 0.1^o in the MSE data).

Recovery of q_{75} with various predictor models

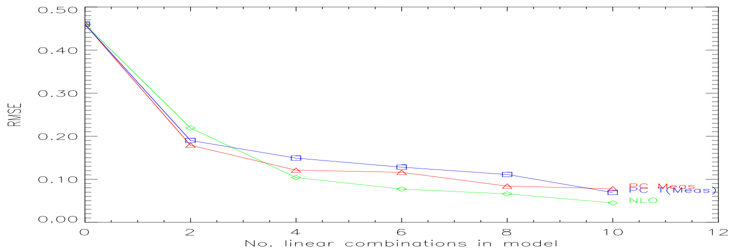


Fig.1 The RMSE for q_{75} for various number of linear combinations (LCs) for the nonlinearly optimised predictors (NLOs) and the principal components (PCs)

The q-profile was recovered using 3 different FP models (1 NLO and 2PC based models) with various of predictors. Fig. 1 illustrates the improvement of the NLO routine verses 2 PC models, the first based on normal measurements and the second based on the 'transformed' measurements for the q75 value. It most be noted that the NLO routine gains most over both PC model with a somewhat less than optimal number of predictors. This helps illustrate that NLO predictors optimises the amount of data better than the equivalent PC models.

Recovery of the q-profile with Magnetic and MSE data

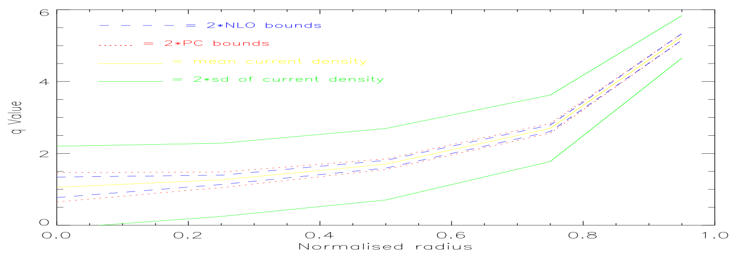


Fig.2 The q-profile recovery with 10 LCs out of 11 transformed magnetic and MSE measurements for both the NLO and PC predictors. These are shown relative to twice the standard deviation of the q-profile over the whole database

The entire q-profile recovery with 10 predictors from 11 transformed measurements is shown in Fig.2 which illustrates the improvement of the NLO model over the PC model by showing twice the RMSE values of each model against the mean of the values themselves in the database and twice the standard deviation of the said values. The NLO model recovers q0 25% better than the equivalent PC model. The errors in both models at q95 are similiarly small with RMSE values of .05.

Recovery of the q-profile with magnetic data only

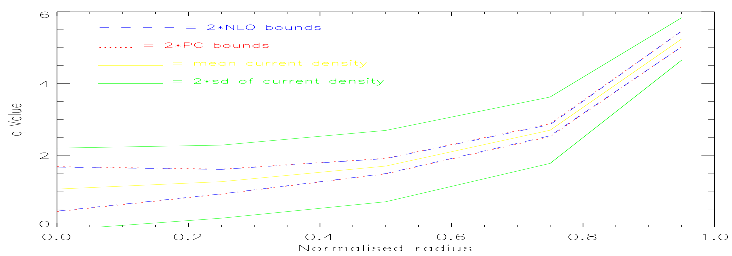


Fig.2 The q-profile recovery with 6 LCs out of 7 transformed magnetic measurements only for both the NLO and PC predictors. These are shown relative to twice the standard deviation of the q-profile over the whole database

For a comparison with an FPG model, the MSE measurements were omitted and the q-profile was again recovered (Fig.3). The errors were approximately twice that of the previous FPJ model.

Current density profile recoveryfrom magnetic and MSE data

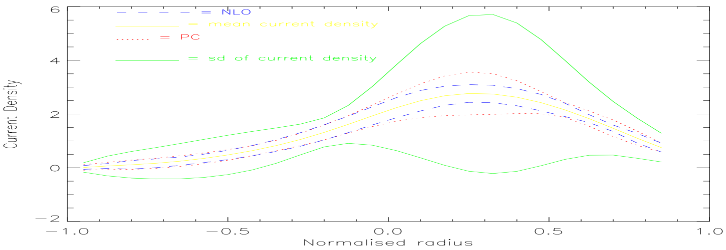


Fig.2 The current density-profile recovery with 10 LCs out of 11 transformed magnetic and MSE measurements for both the NLO and PC predictors. These are shown relative to twice the standard deviation of the current density over the whole database

The j_ρ-profile was recovered using again, 10 predictor from 11 transformed measurements. The centre of the plasma is shifted towards the lowfield side. The mean value of β_{pol} in the database is 1.6 resulting in significant Shafranov shifts. Here again the NLO FP model more accurately recovers the profile (Fig. 4). More interesting to note is the gain in recoverablitiy that the NLO FP routine has over the PC routine at the centre of the plasma. This is where the highest variance of recovered parameter takes place and is analogous to the size of variance in the on-line equilibrium database.

Conclusion and Future Work

Initial results have shown that the NLO FP process optimises the available data better than the standard PC model. The database was restricted so it is still unclear as to how much the NLO will gain over the PC model in the realtime equilibrium database. The addition of the MSE data substantially inproved the accuracy of the j_ρ, q profile recovery.

Future work involves creating a NLO FP model for the realtime equilibrium database, this model will be tested offline in preparation for on-line application.

References

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