ON THE POSSIBILITY OF q-PROFILE MEASUREMENT BY OBSERVATION OF PELLET ABLATION BY A FAST-FRAMING CAMERA AT ASDEX UPGRADE

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INTRODUCTION

Knowledge and control of the current density distribution and/or the profile of the safety factor q is of great importance for controlled thermonuclear fusion research on tokamaks. Mechanisms of transport processes and different instabilities are assumed to base on the connection between such processes and the q-profile. Interpretation and future active control of improved stability and confinement as well as control of bootstrap current with respect to advanced and possible continuous tokamak operation consequently requires information on the q-profile. Unfortunately, this plasma property is one of the most difficult to measure.

The method applied for the studies at ASDEX Upgrade is based on multiframe photography of cold plasma clouds near an ablating pellet. When injecting a deuterium pellet for particle refuelling into a hot plasma, the ablating material fills a spatial sequence of flux tubes following the magnetic field lines. Inside the flux tube, a cold, dense, high collisional plasma, containing a small fraction of neutrals, emits visible light after undergoing collisional excitation. Therefore, it is possible to observe the flux tubes passed by the pellet by means of a fast-framing camera. From these pictures the inclination angle of the magnetic field may be determined with respect to the torus midplane. Due to the application of a photographic camera for the investigations presented here, an adequate data analysis is very time consuming. A novel cooled 2D CCD camera detector that is currently developed[1], will greatly improve the performance of this experiment.

EXPERIMENTAL ARRANGEMENT AND DATA ANALYSIS TECHNIQUE

A scetch of the experimental arrangement is given in figure 1. Pellets are injected by means of a centrifuge injector horizontally near the midplane of the torus. By variation of pellet mass and/or velocity the pellet penetration depths into the plasma, which determines the radial range for the q-profile measurement, can be adjusted. Since pellet velocity is measured accurately, a precise localization $\mathbf{R}(t)$ of the pellet is possible at each time.

Via a window directly above the pellet injection port, nearly the whole injection path can be observed by the fast-framing camera; the camera's line of sight is slightly tilted with respect to the pellet injection path. The light is emitted inside the ablation cloud, passes through the observation window and is then directed via mirrors onto the cameras entrance lens. The image is further directed via a constantly rotating mirror onto one of 72 circular arranged lenses and finally focussed on the film. The ablation cloud image passes one lens within 4 μs; when the recording is finished, a series of up to 72 ablation cloud pictures has been imaged on the film. The total sequence covers a period of about 280 μs with each frame averaging the evolution within 4 μs. The light flux is controlled by a shutter mounted just behind the entrance lense.

For the analysis, the exposed film is developed and scanned to yield a digitized 2D intensit distribution of each frame. The inclination angles of the ablation clouds are determined b processing the digitized intensity distribution using two different methods. The first method fi a straight line to the points of maximum intensity, the second method calculates the princip axis of the intensity distribution. A check is performed by comparing results obtained by bot methods. A good coincidence of the inclination angles using both analysis methods was found This indicates correct determination of the angle. For each frame, the mean value of both value is adopted as α_M. Using it's recording time, the frame's radial position can be determined an hence the experimental values $\alpha_M(\mathbf{R})$ are obtained.

RESULTS AND DISCUSSION

With the knowlege on the radial profile of the magnetic field line inclination angle, the purpos is to determine the safety factor profile. It is easy to obtain q(R) from a given $\alpha_M(\mathbf{R})$ profil for example in the case of circular, concentric flux surfaces, where it can be calculated directl to be

$$q = \frac{r}{R_0} \times cot(\alpha_M)$$

However, since

$$q = \frac{1}{2\pi} \oint_{\psi_p} \frac{B_t}{R \cdot B_p} ds_p$$

is a global parameter and $\alpha_M(\mathbf{R})$ is a local value, the problem shows growing complexity with additional plasma shaping efforts. For an elongated plasma with triangularity as in ASDEX Upgrade, detailed knowledge on the plasma geometry is required for the q(r) reconstruction. Although there have been efforts to derive equations for an approximate calculation[2], the accur-racy when using the analytic expressions for a direct calculation of q(R) decreases rapidely with increasing complexity of the plasma geometry. In our case, results were not satisfactory when using these analytic expressions. Consequentely, we determined the field line inclination angle $\alpha_{EC}(\mathbf{R})$ using a plasma equilibrium code and compared the results with the measured values $\alpha_M(\mathbf{R})$. The result is plotted in figure 2, where the triangles represents the $\alpha_{EC}(\mathbf{R})$ values, the crosses result from the camera measurements. Error bars indicate the uncertainty of each data point. The maximum possible error resulting from the error in the penetration depth o the pellet is identical to the uncertainty in the radial position of the whole measurement. This error is represented by the bar in the lower left corner. As can be recognized from figure 2 the measured field line inclination angles are in good agreement with those from the plasma equilibrium reconstruction at the plasma edge but show a growing discrepancy with increasing distance from the separatrix towards the plasma centre. This means the q-profile obtained by the equilibrium code is in agreement with the real field line inclination near the seperatrix bu drops too rapid; the measured field line inclination in the plasma centre indicates higher q values there. In figure 3 the q-profile from the equilibrium code is plotted as solid line. The dashe line refers to a equilibrium estimated from the performed measurement of $\alpha_M(\mathbf{R})$.

The discrepancy between the equilibrium code and the camera measurements however can b due to the equilibrium code's decreasing accurancy towards the plasma centre. For the calcula-tion of the equilibrium, the applied algorithm tries to find the most likely equilibrium plasm configuration which reproduces measurements of coils mounted at the tokamaks vacuum vesse These signals are dominated by the magnetic conditions near the plasma surface. As the distanc to the coils is greater and the volume is smaller, the plasma central region signal contributio is small compared to that one of the edge region. Consequentely, the equilibrium reconstructe is more accurate for the edge region where its reliability drops with decreasing distance to the plasma centre.

CONCLUSION

We found that the ablation clouds of evaporating pellets injected for the purpose of plasma refueling can be used to visualize magnetic field lines. For the plasma boundary region the measured inclination angles are in excellent agreement with those obtained using the equilibrium code based on the magnetic coil data. As for the plasma boundary the code is most accurate we consider the cameras measurement determines the inclination angle correctly. For the plasma regions closer to the plasma centre, the discrepancy is most probably caused by the decreasing sensitivity of the equilibrium code to this region. Whereas the accuracy of the q values strongly decreases for the equilibrium code analysis, it remains almost constant for the $\alpha_M(\mathbf{R})$ measurement with decreasing distance to the plasma centre. Moreover, the q-profile deduced from the $\alpha_M(\mathbf{R})$ data is supposed to be more accurate than the q-profile from the equilibrium code. Figure 4 shows the reduction of the normalized experimental error margin $\frac{\Delta j}{\Delta j_{axis}}$ and $\frac{\Delta q}{\Delta q_{axis}}$ when including the $\alpha_M(\mathbf{R})$ data to the code input data (stars) in comparison with magnetic coil data only.

Thus, although it cannot yield a satisfactory determination of q-profiles on its own in complex plasma configurations, the technique of measuring field line inclination angles by observation of pellet clouds with a fast framing camera can significantly improve the accuracy of a q-profile reconstruction when combined with another method. As shown here, combination of the local measurement of the inclination angles with the equilibrium code analysis can improve the result obtained substantially.

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REFERENCES

[1] I.V. Miroshnikov, Rev. Sci. Instrum. **66**, 389 (1994).
[2] TFR Group, Europhys. Lett., **2**, 267, (1986).
TFR Group, Nucl. Fusion, **27**, 1975 (1987).
S.M. Egorov et al., JETP Lett., **46**, 180 (1987).
R.D. Durst et al., Rev. Sci. Instrum. **59**, 1623 (1988).

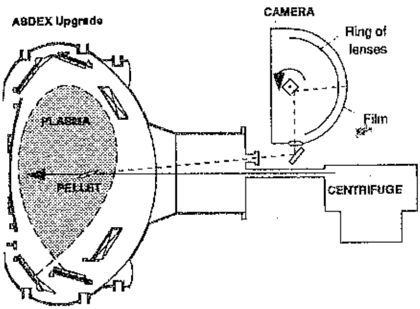

Figure 1

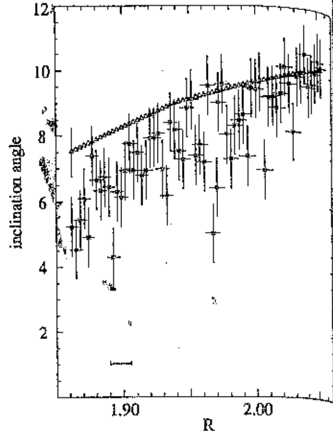

Figure 2

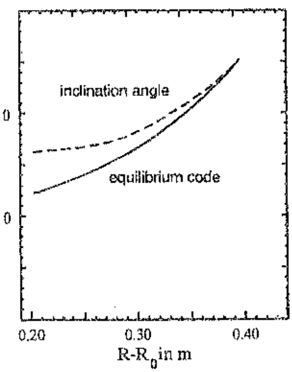

Figure 3

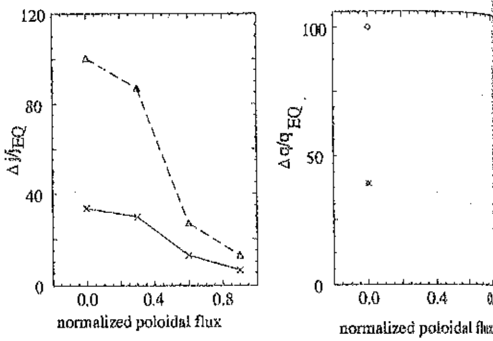

Figure 4

Fig 1: *Experimental setup*

Fig 2: *α_M compared to α_{EC}.*

Fig 3: *The solid line shows the q-profile calculated by the equilibrium code, the dashed line an estimation for the q-profile based on α_M.*

Fig 4: *Reduction of error in current density (j) and q when including α_M to the equilibrium code (stars) with respect to the errors in j and q calculated without α_M measurements.*