34th EPS Conference on Plasma Phys. Warsaw, 2 - 6 July 2007 ECA Vol.**31F**, P-5.078 (2007)

Optimization of the viewing chord arrangement of the ITER poloidal polarimeter

T. Yamaguchi[1], Y. Kawano[1], H. Fujieda[1], K. Kurihara[1], M. Sugihara[2] and Y. Kusama[1]

[1]*Japan Atomic Energy Agency, Naka, Japan*

[2]*ITER Organisation, Cadarache, France*

1. Introduction

The poloidal polarimeter, which is based on the measurement of the Faraday rotation angle, will be installed in the International Thermonuclear Experimental Reactor (ITER) to diagnose the safety factor profile, *q*(*r*), in the plasma core region. At the existing design, the numbers of viewing chords are restricted to about 9 channels for the equatorial (EQ) port and 6 channels for the upper (UP) port because of the limitation of the geometric capacity [1]. But the optimum arrangement of limited viewing chords to achieve the high measurement accuracy had not been investigated. For the optimization of the viewing chord arrangement, as the first step, we have studied a sensitivity of the viewing chord arrangement on the current profile [2, 3]. Based on those studies, we optimized the viewing chord arrangement by the evaluation of the magnetohydrodynamic (MHD) equilibrium reconstruction in this study.

2. Development of MHD equilibrium reconstruction method

Most of the MHD equilibrium reconstruction methods assume the isotropic pressure plasma. But it has been reported that the equilibrium of the anisotropic pressure plasma is significantly different from the equilibrium of the isotropic pressure [4, 5]. The reconstruction method developed for this study has a potential to reconstruct MHD equilibria with a good accuracy even in case of the anisotropic pressure because it does not use information of the pressure.

We express the topology of the magnetic flux surfaces as the relations [6]:

$$R = R_0(\hat{\psi}) + a(\hat{\psi})\cos(\theta + \delta(\hat{\psi})\sin\theta) \quad (1)$$

$$Z = Z_0(\hat{\psi}) + a(\hat{\psi})\kappa(\hat{\psi})\sin\theta \quad (2)$$

where $\hat{\psi}$ is the normalized poloidal flux, $a(\hat{\psi}), \delta(\hat{\psi})$ and $\kappa(\hat{\psi})$ are the minor radius, the triangularity and the elongation, respectively. The centres of surfaces are expressed by $R_0(\hat{\psi})$ and $Z_0(\hat{\psi})$. Those flux surface functions are shown as simple series using free parameters, for example, $a(\hat{\psi})$ and $\kappa(\hat{\psi})$ are shown as:

$$a(\hat{\psi}) = \frac{a_{lcfs}}{M_a}\left\{\sum_{i=1}^{M_a}\left(1-\hat{\psi}^i\right)^{a_i}\right\} \quad (3)$$

$$\kappa(\hat{\psi}) = \kappa_{lcfs} + \sum_{i=1}^{M_b}\left(b_i\hat{\psi}^i\right) \quad (4)$$

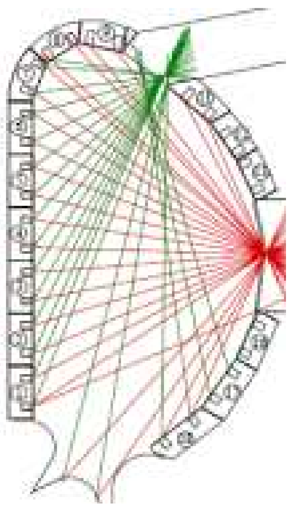

Fig.1 All candidates of viewing chords.

where a_i and b_i are free parameters, subscript 'lcfs' means topological parameter at the last closed flux surface (LCFS), which are evaluated from the LCFS shape. The LCFS shape is treated as the given condition in this analysis because it can be well identified from the magnetic diagnostics [7]. The absolute value of the poloidal flux is also the free parameter. If free parameters were given, the poloidal flux distribution can be calculated. The magnetic field along the viewing chords, $B_{||}$, can be calculated from the poloidal flux. Then the Faraday rotation angle is obtained from

$$F^{cal} = C\lambda^2 \int n_e B_{||} dl \qquad (5)$$

where C is a constant, λ is the laser wavelength and the integral is taken along the viewing chord. In this study, the n_e at viewing chord is treated as the given condition. The free parameters are evaluated by minimizing the $\chi^2 = (F^{cal} - F^{mes})^2$, where F^{mes} is the measured Faraday rotation angle. It is the advantage of this method that all free parameters for the absolute value of the poloidal flux and for the topology of the internal flux surface are determined by F^{mes} only. In this study, F^{mes} are calculated from the equilibria of the Tokamak Operation Scenario and Circuit Analysis code (TOSCA) and $n_e = 10^{19} + 10^{20} (1 - \rho^{10})$. The identified accuracy of $q(r)$ is affected not only by the viewing chord arrangement but also the degree of series, for example, M_a and M_b in Eq. (2). The too small number of them decreases the accuracy, otherwise the too large number of them occurs the oscillation of the identified $q(r)$, namely, ill-posed problem. Similar phenomenon has been reported in other studies, for example [5]. In this study, the numbers of degree of series which gave best accuracy were chosen from the result of scanning the numbers of degree.

3. Optimization of viewing chord arrangement

Figure 1 shows the poloidal cross section of the ITER with present all candidates of viewing chords. The viewing chords are based on the positions of retroreflectors (RRs), which are assumed inside the remote handling slots of the blanket modules (BMs) in this study, and possible first mirror positions. We made various arrangement patterns consisting of 15 channels from those chords and evaluated the accuracy of the identified $q(r)$. At first, the start of burn phase of ITER operation scenario 2 (S2-SOB) which is the inductive operation, was analyzed. The Faraday rotation angle of viewing chords of the EQ port, can be expressed as the profile of the poloidal angle. We selected 9 channels from the EQ port, which are typical channels to express the Faraday rotation angle profile as the poloidal angle [3]. We also selected the 6 channels from the UP port, which through near the magnetic axis, because we have reported that the viewing chords from the UP port are useful to detect the magnetic axis shift [2]. Figure 2 (a) and (b) show the result of the reconstruction using those viewing chords. The difference between the q value at the magnetic axis, q_0, by TOSCA and q_0 by the reconstruction was 35 %. We evaluated χ^2 of all candidates of viewing chords in order to investigate the reason of the bad accuracy. We found that χ^2 is large value at the peripheral region which is shown as 'A' in Fig. 2 (a). A simple idea to improve the accuracy is a movement of viewing chords of the EQ port to the 'A' region. Using this idea, the accuracy of q_0 was improved to 5 %. Furthermore, we considered an alternative arrangement. The positions of RRs for the 'A' region's chords are inevitably near from the BM's surface. The deep positions of RRs are better from the point of view of the degradation of the RR's reflectance due to the sputtering and the coating by the plasma. Therefore we moved one of the UP viewing chords into the 'B' region, for which the retroreflectors can be embedded deeply into the BMs. The result is shown in Fig. 2 (c) and (d) in which the q_0 accuracy of 3 % was achieved. Secondly, the start of burn phase of ITER operation scenario 4 (S4-SOB) which is the non-inductive operation, was analysed. We have reported that viewing chords in the central region which is the region 'D' shown in Fig. 2 (e) and the middle region which is shown as 'C', are sensitive to the current profile of the negative magnetic shear plasma [2]. The results using the arrangement are shown in Fig. 2 (e) and (f). The accuracy of the minimum q value, q_{min}, was within 1 % and the accuracy of q_0 was 2 %. Furthermore, we used the arrangement shown in Fig. 2 (c) for the analysis of S4-SOB. The viewing chord arrangement in Fig. 2 (c) is a promising candidate because the S2-SOB is one of most

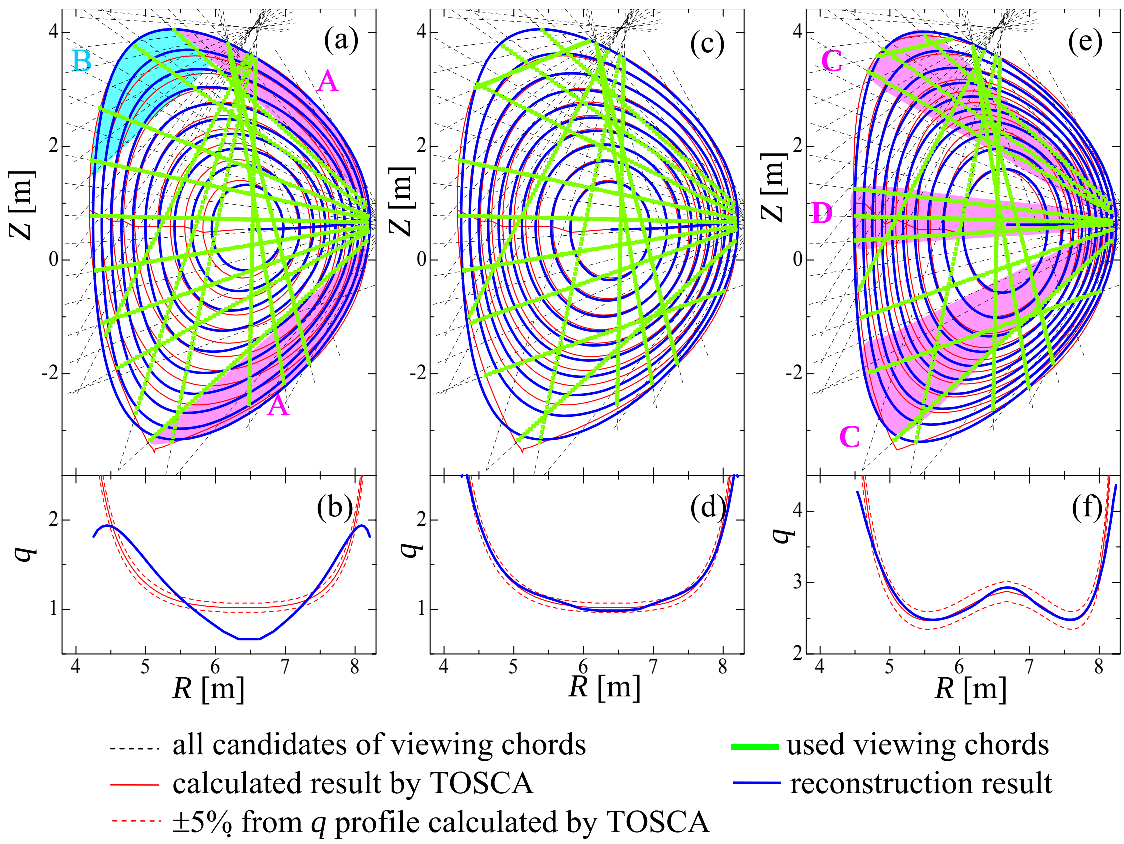

Fig. 2 The results of the reconstruction.

important equilibria in ITER. As the result, the accuracies of q_0 and $q_{\min}$ were 6 % and within 1 %, respectively. Finally, the equilibrium whose net toroidal current is 3.5MA in ITER operation scenario 2 (S2-35), was analysed as the typical limiter plasma during the current ramping up phase. The viewing chord in the region 'B' is out of plasma because the plasma cross section is small. But as the result of the analysis using the viewing chord arrangement shown in Fig. 2 (c), the accuracy of q_0 was within 5 %. The reason of good accuracy not using the viewing chord in the region 'B' is thought that some viewing chords of the EQ port are relatively near to the peripheral region because the limiter point is high field side and the cross section of the S2-35 is small.

4. Future works

The analyses for various equilibria in ITER operation scenario are necessary. The method to identify n_e at viewing chord from the measurement data of other diagnostics (e.g. Thomson scattering) or from the measurement of Cotton-Mouton effect is also one of future works.

5. Discussion

The reconstruction method described in this paper was useful for the optimization of the viewing chord arrangement. To apply this method for the actual experimental data analyses, other method to solve the ill-posed problem is necessary because the adequate numbers of degree of series will not be known. For example, the introduction of the Tikhonov regularization technique [5] may be useful for that.

6. Conclusion

We developed the reconstruction code which can determine all free parameters of internal magnetic surface topology from F^{mes}. Using that, we successfully optimized the viewing chord arrangements for equilibria which are S2-SOB, S4-SOB and S2-35. As the result of using those arrangements, the accuracy of q_0 within 3 % was achieved. Furthermore, the viewing chord arrangement, which was optimized for S2-SOB, was applied for other equilibria. We found that the deteriorations were small (the accuracies of q_0 were within 6 %).

References

[1] A.J.H. Donné et al., Rev. Sci. Instrum. **75**, 4694 (2004)
[2] T. Yamaguchi et al., Plasma Fusion Res. (in press)
[3] T. Yamaguchi et al., JAEA-Research (to be submitted)
[4] T. Yamaguchi et al., Nucl. Fusion, **45**, L33 (2005)
[5] W. Zwingmann et. al., Plasma Phys. Control. Fusion **43**, 1441 (2003)
[6] L. Zabeo et. al., Plasma Phys. Control. Fusion **44**, 2483 (2002)
[7] K. Kurihara et. al., Fusion Eng. Des. **72**, 527 (2005)