Journal of the Physical Society of Japan
Vol. 51, No. 5, May, 1982, pp. 1644–1646

Dependence of Plasma Properties on Elongation Ratio in Non-Circular Tokamak TNT-A

Shunjiro SHINOHARA, Isao OCHIAI, Shunji TSUJI and Hiroshi TOYAMA

Department of Physics, Faculty of Science, University of Tokyo, Bunkyo-ku, Tokyo 113

(Received December 17, 1981)

The relation between the plasma properties and elongation ratio is studied in a non-circular tokamak in the case of the safety factor $q_a \sim 2$. With the increase of elongation ratio κ (1.3→1.5), the plasma current increases from 19.5 to 25 kA, the loop voltage decreases from 4 to 3 V, the mean current density and the electron temperature increase slightly (~10%), while the relative amplitude and the poloidal dependence of Mirnov oscillations ($m=2$ mode) change little.

It is expected that better plasma parameters can be obtained, using a vertically elongated plasma.[1-3] The measurements in TOSCA[4] show that the energy confinement time and the poloidal beta value increase with elongation ratio. The results from Doublet IIA[5] show the enhancement of the electron density and the energy confinement time with increasing elongation ratio. The maximum plasma current increases almost linearly with elongation ratio in Doublet III.[6]

In this letter, the relation between the plasma properties and elongation ratio obtained on TNT-A (Tokyo Non-circular Tokamak)[7-9] is presented. In the case of a cylindrical plasma with the elliptical cross section and flat current density, the plasma current I_p and the current density j are proportional to $(1+\kappa^2)/2$, $(1+\kappa^2)/2\kappa$, respectively, when the safety factor q_a, the toroidal magnetic field B_t and the plasma minor radius a are constant ($\kappa=b/a$: ratio of vertical to horizontal semi axis length). It is considered that the increase of the current density leads to a rise in the electron temperature due to the increased joule heating. In addition to investigate the dependence of the plasma parameters on the elongation ratio, the MHD instabilities must be studied in connection with the confinement properties.

The TNT-A device has major radius $R_0=40$ cm and $B_t \leq 4.4$ kG. The plasma volume is limited by a molybdenum limiter with a D-shaped aperture, 18 cm wide and 36 cm high. The plasma shape is controlled by an external shaping field generated by eight shaping coils surrounding the chamber. The electron temperature and density are measured by Thomson scattering equipment and 70 GHz microwave interferometer. The magnetic surface outside the plasma is determined by 14 magnetic probes and six ψ loops. The signals of Mirnov oscillations are sampled by the micro-computer data acquisition system (sampling time is 1.3 μs) and are analyzed by the fast Fourier transform method.

Elongation ratio κ is varied from 1.3 to 1.5, changing the decay index n_x from -0.15 to -0.75 ($n_x=-(R/B_z)(\partial B_z/\partial R)$: measured value with no plasma current; B_z: vertical field in the cylindrical coordinate (R, ϕ, z); R, ϕ, z: distance from the major axis, azimuthal angle and distance from the equatorial plane).

Figure 1 shows the dependence of the loop voltage V_l, the safety factor q_a and the maximum plasma current I_p on elongation ratio in the case of $B_t=3.7$ kG and filling pressure $\sim 1.7\times10^{-4}$ Torr. With the increase of elongation ratio, the plasma current increases from 19.5 to 25 kA and the loop voltage decreases from 4 to 3 V. Here, the dotted line shows the expected plasma current with $B_t=3.7$ kG, $q_a=2$ and $a=8$ cm ($I_p=(2\pi a^2 B_t/\mu_0 R q_a)\cdot(1+\kappa^2)/2$). The safety factor is lowered to ~ 2 in all four cases. In these cases the plasma density is $4\sim7\times10^{12}$ cm^{-3}.

Figure 2 shows the experimental values of the mean current density and the central electron temperature $T_e(0)$ versus elongation ratio. The curve of the mean current density is shown in the upper figure in the case of $B_t=3.7$ kG and $q_a=2$ ($j=(2B_t/\mu_0 R q_a)\cdot(1+\kappa^2)/2\kappa$). The conductivity temperature T_{ec} rises from 95

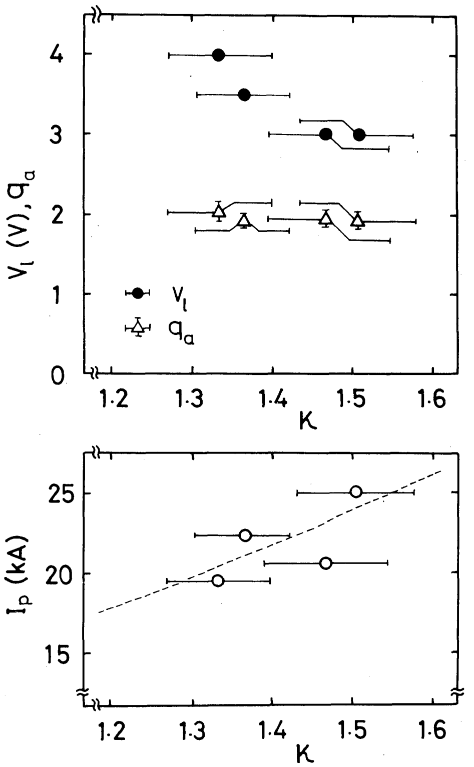

Fig. 1. Dependence of loop voltage V_l, safety factor q_a and plasma current I_p on elongation ratio κ. The dotted line shows the expected plasma current in the case of $B_t=3.7$ kG, $q_a=2$ and $a=8$ cm. ($I_p=(2\pi a^2 B_t/\mu_0 R q_a)\cdot((1+\kappa^2)/2)$).

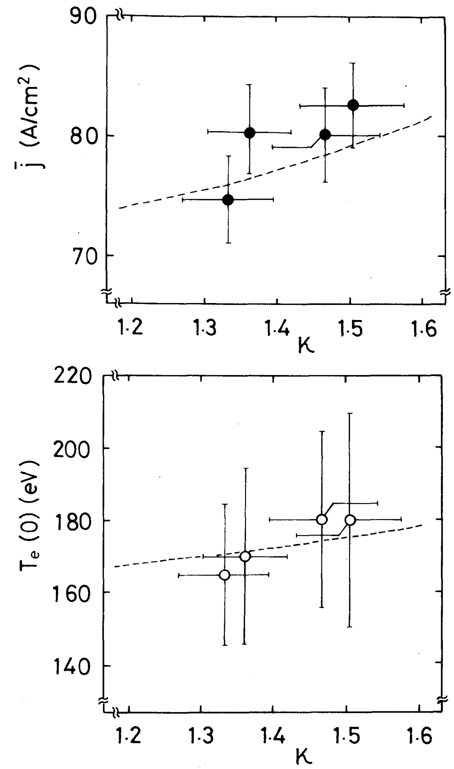

Fig. 2. Plot of mean current density $\bar{j}$ and central electron temperature $T_e(0)$ against elongation ratio κ. The curves of the mean current density ($\bar{j}=(2B_t/\mu_0 R q_a)\cdot((1+\kappa^2)/2\kappa)$) in the case of $B_t=3.7$ kG and $q_a=2$, and the best fit electron temperature T_e, assuming $T_e \propto j^{2/3}$ and $j \propto (1+\kappa^2)/2\kappa$, are also shown.

to 120 eV as κ is changed from ~ 1.3 to ~ 1.5. Here T_{ec} is derived from the measurements of I_p, V_l, κ and a, assuming $Z_{eff}=2.5$[10] (Z_{eff} is the ratio of experimental plasma resistivity to Spitzer resistivity with $Z=1$). The curve in the lower figure gives the best fit electron temperature T_e, assuming $T_e \propto j^{2/3}$ and $j \propto (1+\kappa^2)/2\kappa$. Slight increase of $T_e(0)$ with κ is consistent with the increase of $\bar{j}$ and T_{ec}.

Figure 3 shows a typical example of the poloidal angle (θ) dependence of $\tilde{B}_p/B_p$ (relative amplitude of Mirnov oscillation of $m=2$ mode at the current peak, measured by 12 magnetic probes around the plasma) in the case of $\kappa \sim 1.5$. Here, θ is the poloidal angle from the outer side of the torus. The amplitude of $\tilde{B}_p/B_p$ at the inner side is smaller than that at the outer side of the torus. This difference of $\tilde{B}_p/B_p$ arises because of the small outward shift of the plasma column. There is no enhancement of $\tilde{B}_p/B_p$ at a particular poloidal angle and a clear difference is not found as to the dependence of

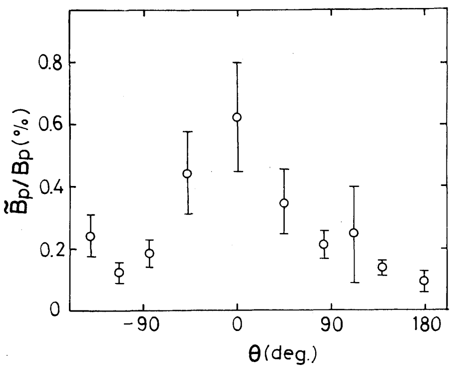

Fig. 3. Poloidal angle dependence of $\tilde{B}_p/B_p$ (relative amplitude of Mirnov oscillations of $m=2$ mode) in the case of $\kappa \sim 1.5$. Here, θ is the poloidal angle from the outer side of the torus.

$\tilde{B}_p/B_p$ profile on elongation ratio, considering the shift of the plasma column.

Figure 4 shows the dependence of the frequency and $\tilde{B}_p/B_p$ of Mirnov oscillations on

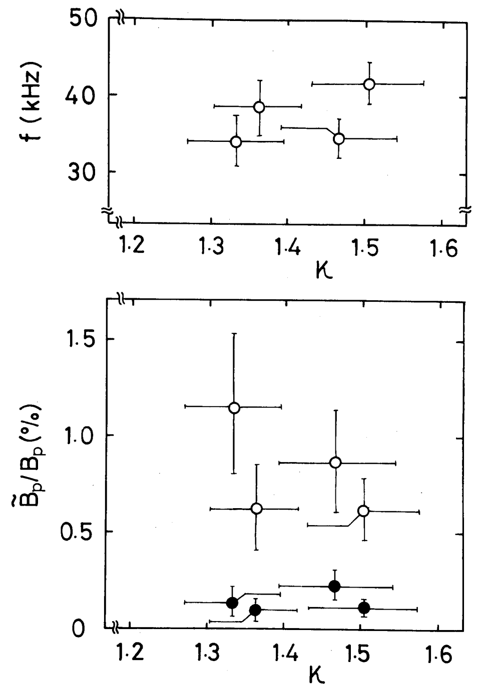

Fig. 4. Frequency f and relative amplitude of $\tilde{B}_p/B_p$ at the outer ($\theta=0°$ (○)) and the inner ($\theta=180°$ (●)) equator of Mirnov oscillations vs elongation ratio κ.

elongation ratio. Here, $\tilde{B}_p/B_p$ is measured at the outer ($\theta=0°$) and the inner ($\theta=180°$) equator. Considering the outward shift of the plasma column and the plasma cross section, the value of $\tilde{B}_p/B_p$ at the plasma surface ($\theta=0°$ and 180°) can be calculated. This value of $\tilde{B}_p/B_p$ at $\theta=0°$ is nearly same with that at $\theta=180°$, and changes little with increasing elongation ratio ($\tilde{B}_p/B_p=1\sim1.5\%$). The frequency shows a tendency to increase with elongation ratio.

In conclusion, the plasma current, the mean current density and the central electron temperature increase slightly with elongation ratio, while the relative amplitude and the poloidal dependence of Mirnov oscillations change little under the condition of $q_a\sim2$.

The authors express their gratitude to Dr. J. R. Wilson for reading the manuscript carefully.

References

1) T. Ohkawa: Kaku Yugo Kenkyu **20** (1968) 557 [in Japanese].
2) D. Dobrott and M. S. Chu: Phys. Fluids **16** (1973) 1371.
3) L. A. Artsimovich and V. D. Shafranov: Pis'ma v Zh. Eksp. & Teor. Fiz. **15** (1972) 72. translation JETP Lett. **15** (1972) 51.
4) D. C. Robinson and A. J. Wootton: Nucl. Fusion **18** (1978) 1555.
5) R. L. Freeman *et al.*: in *Plasma Physics and Controlled Nuclear Fusion Research* (*Proc. 6th Int. Conf. Berchtesgaden, 1976*) (IAEA, Vienna, 1977) Vol. 1, p. 317.
6) JAERI Team: Nucl. Fusion **20** (1980) 1455.
7) H. Toyama *et al.*: in *Plasma Physics and Controlled Nuclear Fusion Research* (*Proc. 6th Int. Conf. Berchtesgaden, 1976*) (IAEA, Vienna, 1977) Vol. 1, p. 323.
8) H. Toyama *et al.*: in *Plasma Physics and Controlled Nuclear Fusion Research* (*Proc. 7th Int. Conf. Innsbruck, 1978*) (IAEA, Vienna, 1979) Vol. 1, p. 365.
9) K. Toi *et al.*: in *Plasma Physics and Controlled Nuclear Fusion Research* (*Proc. 8th Int. Conf. Brussel, 1980*) (IAEA, Vienna, 1981) Vol. 1, p. 721.
10) S. Shinohara, K. Sakuma, S. Tsuji and H. Toyama: J. Phys. Soc. Jpn. **48** (1980) 1051.