277
11-19-79

DR. 315

UC-20 f,g

UNIVERSITY OF WISCONSIN • MADISON, WISCONSIN

PLASMA PHYSICS

EXPERIMENTAL OBSERVATION OF PLASMA PARAMAGNETISM IN A TOKAMAK

by

D.J. Holly, S.C. Prager, M.W. Phillips, and J.C. Sprott

MASTER

C00-2387-115

September 1979

ONSIN

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for any third party's use or the results of such use of any information, apparatus, product or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights.

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS Price codes
Printed copy: A02
Microfiche copy: A01

EXPERIMENTAL OBSERVATION OF PLASMA PARAMAGNETISM IN A TOKAMAK

D.J. Holly, S.C. Prager, M.W. Phillips, and J.C. Sprott
Department of Physics, University of Wisconsin, Madison, Wisconsin

ABSTRACT

The increase in the toroidal magnetic field of a tokamak due to plasma presence is measured experimentally and compared with predictions of an equilibrium code.

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

129

It is well known that tokamaks are diamagnetic at high β and paramagnetic at low β ; i.e., at low β the diamagnetic current ($\sim \nabla B \times B / |B|^2$) is negligible, current flows parallel to the magnetic field ($\mathbf{j} \times \mathbf{B} = 0$) and the poloidal component of the parallel current causes the toroidal magnetic field to increase from its vacuum value. This feature of the equilibrium has not been reported experimentally. It is to be distinguished from the type of paramagnetism that arises in some systems when the plasma induced current ($\nabla p \times B / |B|^2$) is in such a direction as to increase the field. Numerical calculation¹ indicates that the boundary between para- and diamagnetism in a tokamak is roughly $\beta_{\text{poloidal}} \approx 1$ where $\beta_{\text{poloidal}} \equiv 8\pi \langle p \rangle_v - p_0 / \langle B_{\text{poloidal}}^2 \rangle_s$, p_0 is the pressure at the plasma edge and $\langle \rangle_v$ and $\langle \rangle_s$ represent averages over the plasma volume and surface, respectively.

Here we report observation of the paramagnetic effect in the Tokapole II device,² a tokamak with a four null poloidal divertor (Fig. 1). The plasma and field shaping is accomplished by four internal rings which create an octupole vacuum field. The temperature is sufficiently low ($T_e \sim 100$ eV, $n \sim 10^{13} \text{ cm}^{-3}$, $I_p \sim 40$ kA and $B_T \sim 3.5$ kG for this experiment) that a magnetic probe may be inserted into the plasma without serious effect. The measured experimental ΔB_T is shown in Fig. 2. The poloidal current density on the midplane may be inferred from the data ($j_p \sim \frac{1}{R} \frac{(\partial B_T / \partial R)}{\partial R}$).

Results are compared with an equilibrium code which solves the Grad-Shafranov equation $\Delta^* \psi = \partial^2 \psi / \partial r^2 - \frac{1}{r} \partial \psi / \partial r + \partial^2 \psi / \partial z^2 = -\mu_0 r^2 p'(\psi) - FF'(\psi)$ for tokapole geometry. Since $\beta_{\text{poloidal}} \approx .04$ in the experiment $p'(\psi) = \partial p / \partial \psi$ is negligible and may be ignored. $F(\psi) = r B_{\text{tor}}$ is prescribed in the plasma to be $F(\psi) = F_v [1 + g(\psi - \psi_\ell / \psi_m - \psi_\ell)^{\alpha}]$ where ψ_ℓ is the limiting flux surface, ψ_m is the value of the poloidal flux function ψ at the central magnetic axis, α is a shaping parameter set equal to 1.1, g is adjusted to keep the total current

constant and F_v is a constant equal to F in the vacuum region. An initial guess at $\psi(r,z)$ is used to evaluate $F(r,z)$. The operator Δ^* is then inverted subject to the boundary conditions that ψ be constant on the rings and walls. F is recalculated with the new $\psi(r,z)$ and the process is repeated until $\psi(r,z)$ converges. The limiting flux surface, ψ_ℓ , is taken to be the divertor separatrix. The solution for $\psi(r,z)$ and the magnetic surfaces has previously been verified through direct experimental measurements.^{2,3}

The calculation predicts (Fig. 3) the change in toroidal field ΔB_T to be roughly 3.5%. In order to accurately compare with theory which excludes current in the scrape-off region, it is necessary to discount the contribution of current outside the separatrix to ΔB_T . Thus for comparison, ΔB_T should be measured from the dashed baseline drawn in Fig. 3. The ΔB_T below the baseline (which intersects the curve at the separatrix) is due entirely to current outside the separatrix. Experiment and code calculation agree well.

REFERENCES

- ¹J.D. Callen and R.A. Dory, Phys. Fluids 15, 1523 (1972).
- ²A.P. Biddle, R.N. Dexter, R.J. Groebner, D.J. Holly, B. Lipschultz, M.W. Phillips, S.C. Prager, and J.C. Sprott, to be published in Nuclear Fusion.
- ³B. Lipschultz, S.C. Prager, T.H. Osborne, J.C. Sprott, and M.W. Phillips, Phys. Rev. Lett., 43 (1979) p. 36.

FIGURE CAPTIONS

1. Numerical poloidal flux plot of Tokapole II.
2. Experimental measurement of $\Delta B_T/B_T$ vs. distance from main axis. Measurement from dashed baseline eliminates contribution from poloidal current in scrapeoff region.
3. Equilibrium code predictions for the fractional change in toroidal magnetic field $\frac{\Delta B_T}{B_T}$ (solid line) due to plasma and poloidal current density j_p (dashed line) as a function of distance from major axis.

EXTERNAL DISTRIBUTION IN ADDITION TO UC-20

J.W. Flowers, University of Florida
H.S. Robertson, University of Miami, FL
E.G. Harris, University of Tennessee
M. Kristiansen, Texas Technical University
Plasma Research Laboratory, Australian National University, Australia
P.E. Vandenplas, Association Euratom-Etat Belge, Belgium
P. Sankanak, Institute de Fisica-Unicamp, Brazil
Mrs. A.M. Dupas, C.E.N.G., DPh-PFC-SIG, France
M.A. Layau, Centre d'Etudes Nucléaires, France
G. VonGierke, Max-Planck-Institute Für Plasma Physic, Germany
R. Toschi, Associazione Euratom-Cnen Sulla Fusion, Cento Gas Ionizzati, Italy
K. Takayma, IPP Nagoya Imoversotu, Japan
K. Uo, Kyoto University, Japan
K. Yamamoto, JAERI, Japan
B. Lehnert, Royal Insititute of Technology, Sweden
E.S. Weibel, CRPP, Ecole Polytechnique Federale de Lausanne, Switzerland
A. Gibson, Culham Laboratory, UK
R.S. Pease, Culham Laboratory, UK
D.R. Sweetman, Culham Laboratory, UK
J.B. Taylor, Culham Laboratory, UK
D. Schuster, University of Natal, South Africa
G.M. Budker, Siberian Academy of Sciences, USSR
V.E. Golant, IOFFE Physico-Technical Institute, Academy of Sciences, Russia
I.G. Gverdtsiteli, Phisico-Tech. Inst. State Com. for Utilization of Atomic Energy, USSR
B.B. Kadomtsev, Institute of Atomic Energy, USSR
M.S. Rabinovich, Lebedev Institute, Academy of Sciences, USSR
Cheng-chung Yang, Chinese Academy of Sciences, Lanchow, Peoples Republic of China
Chi-shih Li, Chinese Academy of Sciences, Peking, Peoples Republic of China
Hsiao-wu Cheng, Chinese Academy of Sciences, Shanghai, Peoples Republic of China
Yi-chung Cho, Chinese Academy of Sciences, Peking, Peoples Republic of China
Fu-chia Yang, Futan University, Peoples Republic of China
Mei-ling Yeh, Chinese Academy of Sciences, Lanchow, Peoples Republic of China
Wei-chung Chang, Chinese Academy of Sciences, Shanghai, Peoples Republic of China
Kuei-wu Wang, Chinese Academy of Sciences, Loshan County, Peoples Republic of China
Chün-hsien Chen, Chinese Academy of Sciences, Peking, Peoples Republic of China
Li-tsien Chiu, Chinese Academy of Sciences, Peking, Peoples Republic of China
Miao-sun Chen, Chinese Academy of Sciences, Peking, Peoples Republic of China