



stellarator news

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From the Editor...

The Editor is endeavoring to publish the *Stellarator News* every other month. Accordingly, he would appreciate it if contributions to the newsletter would be sent to him so that they arrive at the start of the last full week of the even-numbered months. In addition to experimental results, please also send theoretical summaries, news items, and personnel changes. Contributions for the May issue are due on April 23, 1990.

Please try to send the articles via E-mail. The MFE network is now accessible via Internet and Bitnet from a host of other networks. The appropriate addresses are

From Internet:

ROME%MFE.MFENET@CCC.NMFECC.GOV

From BITNET:

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Please do NOT format your contributions. Leave a blank line between paragraphs and do not indent them. The EQN language should be used for equations. In equations, ~ represent wide spaces, ^ represent narrow spaces, and curly braces group terms. Greek letters should be written out using all lower case or all capital letters as appropriate. Thus, to produce the equation

$$\bar{n}_e \approx 1.0 \times 10^{13} \text{ cm}^{-3}$$

you would enter

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<$En bar sub e ~ approx~ 1.0 ^times^ 10 sup {13}  
roman {^cm} sup {-3}>
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Pictures enliven the articles. The Editor can accept Post-Script, Tektronix, HPGL, Lotus PIC, and Digital Research GEM formats. Remember that the E-mail networks only transmit ASCII files, and the lines must be less than 80 characters long.

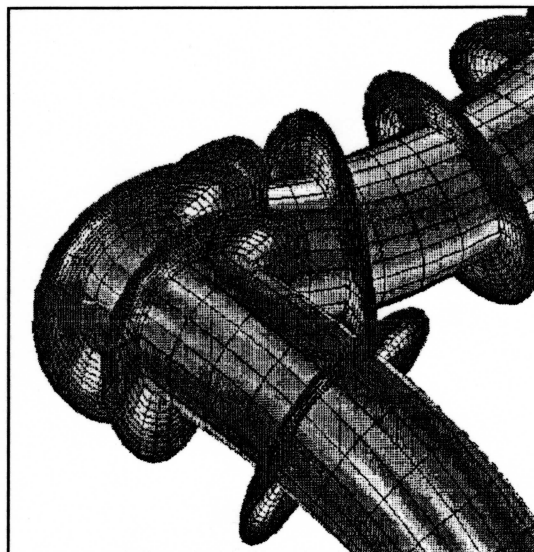
Erratum

In the last issue of *Stellarator News*, the price for the TJ-II Flexible Helicac was incorrectly given as 32,900 MECU. The correct price is 32.9 MECU. The Editor regrets this mistake and thanks Shoichi Yoshikawa for pointing it out.

Cray Gigaflop Contest Won with Stellarator Calculations

A team lead by Anthony Cooper and Ralph Gruber at the École Polytechnique Fédérale de Lausanne, which included David V. Anderson from NMFECC at Lawrence Livermore National Laboratory, won the 1989 Cray Gigaflop Performance Award, achieving 1.708 gigaflop/s on the 3-D MHD stability code TERP-SICHORE. They beat a team from NASA solving Navier-Stokes equations, one from First Boston Corporation doing bond market simulation, and 17 other contestants who surpassed 1 gigaflop/s.

This is of interest to readers of *Stellarator News* because their calculations were done for a four-field-period Helias configuration once considered for Wendelstein VII-X. To achieve this performance level, they used multitasking, vectorization, and extensive pre-compilation macros.



Perturbed pressure distribution in an unstable, magnetically confined 4-field-period Helias. The calculations were performed using the TERPSICHORE code at Lausanne. This visualization shows the constant j and k surfaces.

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Around the Labs

Wendelstein VII-AS Operates at B = 2.5 T

After modifications to the support elements of certain coils of the W VII-AS modular coil system, the experiment presently operates at a magnetic field of 2.5 T. Coil motions seen at critical positions in earlier experiments at half field are now smaller, and the prospects of coil performance look good for the future. No restrictions are seen that limit operation of the experiment over the whole range of rotational transform values.

Present experiments concentrate on exploring the regions of 'good' confinement, e.g. at an edge value of $\iota > 1/2$. The figure shows profiles of electron density and temperature obtained in two series at $\iota(a) \approx 0.51$, using ECRH at 70 GHz (O-mode at 2.5 T) with 180 kW (open points) and 300 kW (closed points) of applied heating power. The peak temperatures are 1.5 and 1.7 keV; the peak density of $0.4 \times 10^{20} \text{ m}^{-3}$ has been kept constant. The density profiles are slightly hollow; density and electron temperature profiles are slightly broader at increased heating power. The resulting χ_e profiles are being analyzed. For these two series, values of the stored plasma energy of 2.8 and 4.8 kJ were measured by the diamagnetic loop.

Ongoing experiments are concentrating on the topics of papers to be presented at the 17th European Physical Society Conference in Amsterdam, 25 – 29 June 1990, by the following leading authors:

Invited paper

H. Ringler: Confinement Studies on the W VII-AS Stellarator

Contributed papers

G. Kuehner: Statistical Analysis of Electron Heat Conduction on W VII-AS

J. Junker: Ion Heat Conduction, Radial Electric Field and CX-Losses in the W VII-AS Stellarator

V. Erckmann: Current Drive and Wave Absorption Experiments at the Electron Cyclotron Frequency

U. Gasparino: Non-inductive Currents in W VII-AS: Experimental Results and Theoretical Modelling

W. Ott and F.P. Penningsfeld: First Results with Neutral Injection into the W VII-AS Stellarator

A. Weller: Results from X-Ray Measurements on the Wendelstein VII-AS Stellarator

M. Tutter: On Density and Temperature Fluctuations Observed by ECE Diagnostics in Wendelstein VII-AS

H.J. Hartfuss: Reflectometry Observations of Density Fluctuations in the Wendelstein VII-AS Stellarator

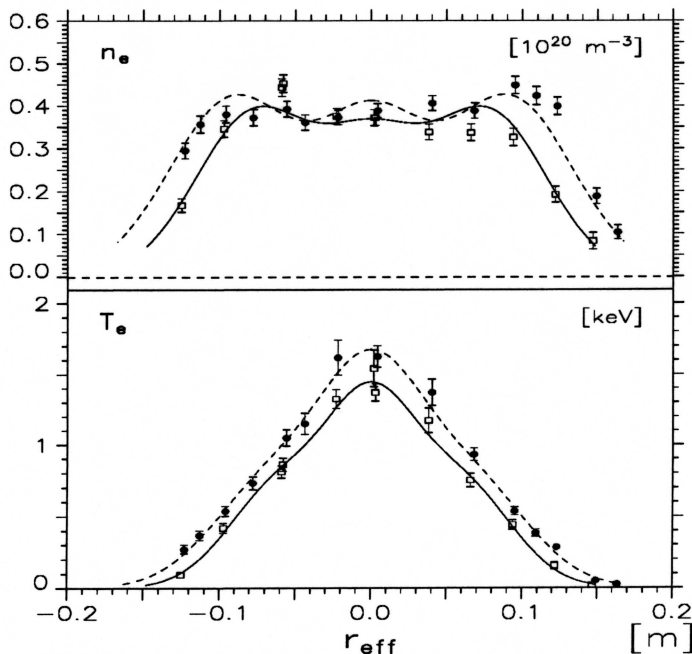
A. Dodhy: H_α Spectroscopy on Stellarator W VII-AS

F. Sardei: Neutral Density Distribution and Particle Diffusion in the Wendelstein VII-AS Stellarator

F. Rau: On the Edge Structure of the W VII-AS Stellarator

C.D. Beidler: A General Theory of Imfp Neoclassical Transport in Stellarators.

F. Rau for the W VII-AS Team
Max Planck Institut für Plasmaphysik
D8046, Garching bei München
Federal Republic of Germany



W VII-AS profiles

shots:

7159– 7172 ————

7333– 7348 - - - -

shots	B_0 [T]	ι_a	W_d [kJ]	P_h [kW]
7159	2.53	0.510	2.83	180
7333	2.53	0.519	4.84	300

Recent Results from ATF

With more thorough titanium gettering (up to 7 getters), low-Z impurities (carbon and oxygen) are now at a negligible level. With gettering and carefully tailored gas puffing, quasistationary neutral-beam-heated discharges of over 0.15 s (with both density and temperature nearly constant) have been obtained (Fig. 1). The discharges were terminated only by the end of the neutral beam heating pulse (300 ms). At present, only one neutral beam line is available. When the second beam line is available, the two will be used together to obtain a heating pulse of 600 ms to test the duration limits of the stationary plasma phase. It is expected that longer pulse heating by ion cyclotron heating with 1 MW of power will be available on ATF in 1991.

Target plasmas have been successfully created with third harmonic electron cyclotron heating (ECH) at low field ($B = 0.63$ T). A typical discharge is shown in Fig. 2. As in earlier work on Heliotron-E, the ECH power was applied to a seed plasma that was created by loop voltage generated during ramping up of the helical coil current. This combination created a currentless target plasma of $\bar{n}_e = 1 \times 10^{19} \text{ m}^{-3}$. Injection of 1-MW neutral beam heating power produced $\langle \beta \rangle = 0.85\%$ and $\bar{n}_e = 4.2 \times 10^{19} \text{ m}^{-3}$ at $B_T = 0.63$ T. When the second neutral beam line is available again, these low B_T discharges will be used to extend the operating envelope of ATF.

Tom Jernigan for the ATF Group
Fusion Energy Division, Oak Ridge National Laboratory
P.O. Box 2009, MS 8072
Oak Ridge, TN 37831-8072 USA

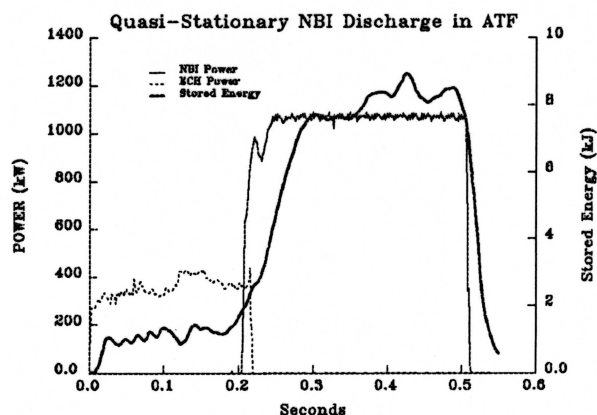


Fig. 1 Quasi-stationary NBI discharge in ATF

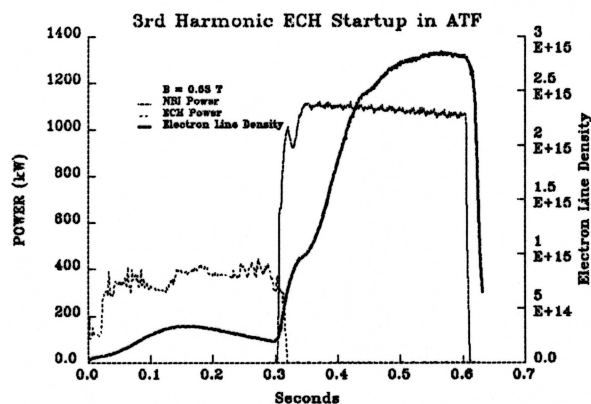


Fig. 2 Third harmonic ECH discharge in ATF

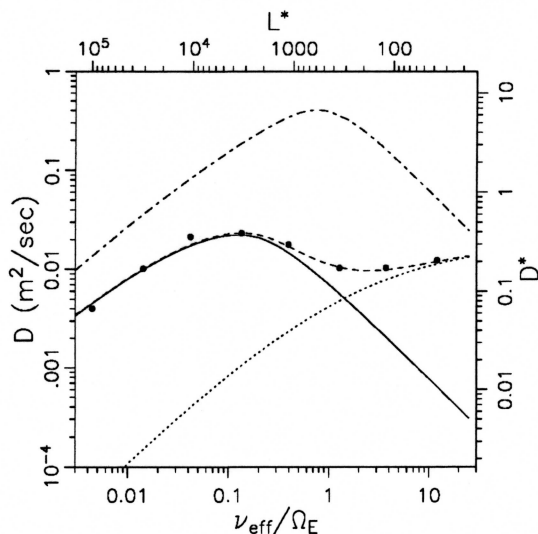
Neoclassical Transport Calculations for the Helias Configuration HS5-10

Continuing optimization studies for Wendelstein VII-X have led to a configuration designated HS5-10, a five-field-period Helias with a major radius of 5.5 m and 10 modular coils per field period. The level of neoclassical transport to be expected in HS5-10 has been determined both analytically and numerically in all collision frequency regimes; results for the flux surface at half the plasma radius may be summarized as follows:

- (1) In the plateau regime the transport coefficients are reduced by a factor of four over those of the equivalent classical stellarator. (The equivalent classical stellarator is defined to have the same aspect ratio, rotational transform, and magnitude of the helical ripple as HS5-10.)
- (2) Transport optimization of Helias configurations is most pronounced in the $1/\nu$ regime; the reduction for HS5-10 in this regime is 80. Expressed differently, a conventional stellarator would have to have a helical ripple of <0.005 to achieve a similar result in this regime.
- (3) The maximum value of the transport coefficients is a factor of 20 smaller than the corresponding quantity in the equivalent classical stellarator.

(4) At the lowest collision frequencies investigated (corresponding to a 90° collision frequency of 0.1 s^{-1}) the reduction factor is 3.

These results are shown graphically in the figure as a plot of the ion diffusion coefficient, D , versus effective collision frequency normalized to the $\mathbf{E} \times \mathbf{B}$ precessional frequency. Alternately, the second set of axes presents the results in terms of the diffusion coefficient normalized to the tokamak plateau value, D^* , and the mean free path normalized to half the connection length, L^* . The solid curve gives the expected value of D due to localized particles and was obtained from a general analytic solution of the bounce-averaged kinetic equation. The dotted line is an estimate of the diffusion coefficient in an "axisymmetric" HS5-10; the dashed line is the sum of the solid and dotted lines. The dot-dash curve is the expected transport level due to localized particles for the equivalent classical stellarator. These analytic predictions are confirmed by the results of Monte Carlo numerical simulations, which are shown on the plot by solid circles. The neoclassical transport due to very localized particles trapped in the "modular" ripple wells of the HS5-10 magnetic field (arising due to the discrete nature of the modular coils which produce the field) has been calculated as well and can be expressed as the ratio of modular ripple transport to helical ripple transport in the $1/\nu$ regime as a function of the normalized minor radius. Results indicate that modular ripple transport is larger in the outer half of the plasma by as much as a factor of 3. Even so, this is a significant improvement over previous 10-coil Helias configurations and is not expected to lead to a significant degradation of plasma confinement.



Transport in the proposed HS5-10 Helias

News from Auburn University

Construction continues on the Compact Auburn Torsatron (CAT): $R = 53 \text{ cm}$, $\langle a \rangle = 11 \text{ cm}$. CAT has an $l = 2$, $m = 5$ helical coil and an $l = 1$, $m = 5$ helical coil. The winding of the $l = 1$ coil was completed in November 1989. The $l = 2$ coil winding is half completed. The winding of the VF coils is in progress. The scheduled completion date is June 1990. Computer calculations have addressed the magnetic islands caused by three specific error-producing effects at $B = 0.1 \text{ T}$. The effect of the earth's field is to produce a magnetic island having a size on the order of 1 cm wide at the $\tau = 1/2$ surface. The size of this magnetic island can be controlled by shifting the magnetic axis. The analysis of a possible coil feed error showed an insignificant effect. A possible up-down asymmetry in the winding of the $l = 2$ helical coil was considered. By adding an $l = 2$, $\cos \theta$ trim coil, the original unperturbed magnetic configuration was recovered. These studies provide evidence of the flexibility and optimization potential of the magnetic configuration of CAT.

Plasma operation and studies of ICH heating continue on the Auburn Torsatron: $l = 2$, $m = 10$, $R = 58 \text{ cm}$, and $\langle a \rangle = 11 \text{ cm}$. Steady-state plasma production using 500 W of ICH has recently been used to test a frame-type antenna. Efforts to increase the ICH power have been successful. In pulsed mode, power levels up to 32 kW at 1 MHz have been injected into a dummy load.

Cynthia Brooks
Physics Department
Auburn University
Auburn, AL 36849, USA



Meeting Reports

IEA Workshop on Next-Generation Experiments December 7-9 Toki and Nagoya, Japan

This was the second workshop held on this topic; the first was held at Kyoto, July 25-28, 1988, and the next is planned for the week of October 7 in Washington or Oak Ridge. Approximately 25 participants from the United States, Japan, the Federal Republic of Germany, and Spain presented 20 papers on the physics and engineering optimization of next-generation stellarators and relevant research on present experiments.

Three large, next-generation stellarator experiments were discussed:

- Large Helical Device (LHD) with $R = 4$ m, $a = 0.5-0.6$ m, $B = 4$ T, and $P = 20$ MW for 10 s or 3 MW steady state that was recently approved for construction at Toki, Japan.
- Wendelstein VII-X (W VII-X) modular Advanced Stellarator with $R = 5.5$ m, $a = 0.52$ m, $B = 3$ T, and $P = 20-30$ MW that is now in the proposal preparation stage at Garching, FRG.
- Advanced Toroidal Facility II (ATF-II), a low-aspect-ratio torsatron with $R = 2$ m, $a = 0.52$ m, $B = 4-5$ T, and $P = 10-15$ MW that is in the scoping study stage at Oak Ridge.

Significant progress was reported in the development of these devices since the last workshop (1988). The physics optimization studies incorporate more detailed studies of anomalous and neoclassical transport and bootstrap current reduction. The expected performance depends on the scaling of anomalous transport. Even with the pessimistic LHD scaling, the performance goals of these devices should be met. However, more experiments on present devices are needed to improve confinement and refine the transport scaling.

Bootstrap currents have been reduced to low levels (less than 5% of that in an equivalent tokamak) in W VII-X, but could be higher in the higher-shear LHD and ATF-II.

Superconducting coil and vacuum vessel designs have been refined, and the engineering issues have been

better defined. Average current densities in the superconducting winding pack have increased nearly a factor of two to about 5 kA per square centimeter.

Key issues in vacuum vessel design are accommodations for particle and power handling and forces on the vacuum vessel due to currents induced by a fast plasma decay.

Preliminary cost estimates have been made, which have led to reducing the major radius in W VII-X from 6.5 m to 5.5 m and to the probable staging of the field and heating power in LHD.

James F. Lyon
Fusion Energy Division, Oak Ridge National Laboratory
P.O. Box 2009, MS 8072
Oak Ridge, TN 37831-8072 USA