stellarator news

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Meeting Reports

Seventh International Stellarator Workshop Held in Oak Ridge

From April 10 to 14, about 100 scientists from eight countires met in Oak Ridge, Tennessee, for a biennial exchange of ideas. The Workshop was jointly sponsored by the International Atomic Energy Agency and Oak Ridge National Laboratory. The Workshop Proceedings will be published by the IAEA.

Each morning was devoted to oral presentations. In the early afternoons there were poster sessions. These were followed by discussion groups that focused upon areas of interest which cut across specific device boundaries. The subjects for these discussions were:

Instabilities and Fluctuations, Edge Phenomena and Impurities, Electric Field Effects, Transport and Heating, ECH and ICH Startup, Configuration Effects on Confinement, Helical Axis Studies, Advances in Configuration Optimization, Device Engineering Issues, and Bootstrap Current.

In the next few issues of the *Stellarator News*, we will present some of the reports of the discussion groups as summaries of the various areas.

DEVICE ENGINEERING ISSUES

Issues of device engineering for a 'next step' stellarator experiment were discussed after contributions given by O. Motojima for the Large Helical Device (Toki, Japan) and by F. Rau for Wendelstein VII-X (Garching, FRG).

Similar engineering issues arise in these two systems, although they differ in their design: LHD is of the torsatron/heliotron type with continuous helical windings and vertical field coils, and W VII-X uses nonplanar modular coils. Both experiments aim at stationary plasma operation with pulse lengths from 10 s up to several minutes, using ECH, NBI, and/or ICH for startup and heating, at power levels of typically 10 to 20 MW. Such power levels impact the design of the vessel, of the experimental ports, and of divertors or (pumped) limiters, foreseen for particle and impurity control. The admissible heat loads at the neutralizer plates are important.

The coils which provide the confining field and rotational transform are considered to be superconducting. Water-cooled coils would have to operate at rather low current density because of their cooling and would require too much space, in view of the distance between the outermost useful magnetic surface and the first wall. For superconducting coils the first wall is part of the cryostat; otherwise the design of the experimental ports would be rather complicated.

The electromagnetic forces, acting either on continuous helical windings or on nonplanar modular coils, exhibit considerable lateral components which can reach the level of the radial forces. Typical values of the current density (averaged over the coil cross section) are 30 to 50 MA/m^2; the peak fields at the coils are up to 8 T. This value is compatible with NbTi as superconductor. An optimized support scheme (coil casing and intercoil structure) is required to keep the resulting stress and strain values within technical limits. The shear stress present in the winding insulation is often a more stringent limit than the short-sample limit of permissible current density in the conductor. This limit stems from the stability of the superconducting state, and depends, for a given conductor, on magnetic field strength and temperature. Voltage limits must be observed for safe discharge of the coils in case they unexpectedly go normal.

Pool-boiling coils exhibit lower tolerable insulation voltages than do forced-flow conductors. But the latter require a more complex array of helium supply lines. The ORNL and IPP-Garching groups suggested that, according to the experience gained on the Large Coil Task, forced-flow systems appear to be superior to pool-boiling ones.

The refrigeration power for the superconducting coils is determined from the desired time for cooldown (dependent on limits in the temperature differences within the coils and their supporting elements) and by the stationary losses during operation. For coils well shielded against radiation from outside the cryostat and from the first-wall/limiter/divertor surfaces, the heat loads of the current leads are important. Typical values of the refrigeration power are 2 to 7 kW at liquid helium temperature.

Osamu Motojima (Kyoto) and Fritz Rau (Garching)

Around the Labs

Tohoku University Heliac Starts Operation

The TU-Heliac is a small standard heliac without an inner *l*=1 helical winding around the central conductor. The machine was constructed in May 1988 and started operation in July. The machine parameters of TU-Heliac are summarized in Table I.

At first, the shape of the magnetic surfaces at a fixed toroidal angle was investigated by mapping techniques and resistance (or capacitance) methods of the electron beam with 1–μ*s* pulses of 7.5 eV energy. It was confirmed that agreement between experimentally measured surfaces and numerically predicted surfaces has been quite good.

Plasmas are produced using ECRH from a 2.45-GHz (400–μ*s* pulse of 500-W power) microwave source, with typical plasma parameters of $n_e = 10^7$–10^{10} cm^{-3}, $T_e = 2$–5 eV. The working gas is argon at a pressure of 1.4×10^{-2} Pa.

Figure 1 shows the decay of the electron density and temperature after ECRH was switched off. The density and temperature were measured by a Langmuir probe. Soon after ECRH switched off, recombination, which is proportional to n^2, is dominant, and the density decays reciprocally. After the density has reached a low value, diffusion becomes dominant and decay is exponential. The observed average diffusion coefficient is 1.1×10^3 cm^{2}s^{-1} for $B_T = 0.88$ kG. This value is 20 times less than that of the Bohm diffusion.

H. Watanabe, S. Kitajima, and N. Takeuchi
Faculty of Engineering, Tohoku University
980 Sendai, Japan

No. of field periods	4
Major radius (m)	0.48
No. of TF coils	32
Mean TF coil radius (m)	0.19
TF coil swing radius (m)	0.08
VF coil location (m)	R = 0.9 Z = ± 0.3
Max. Central Ring current (kAT)	100
Flat top of CR current (ms)	12
Flat top of VF coil current (ms)	12
Flat top of TF coil current (ms)	20

TABLE 1: TU MACHINE PARAMETERS

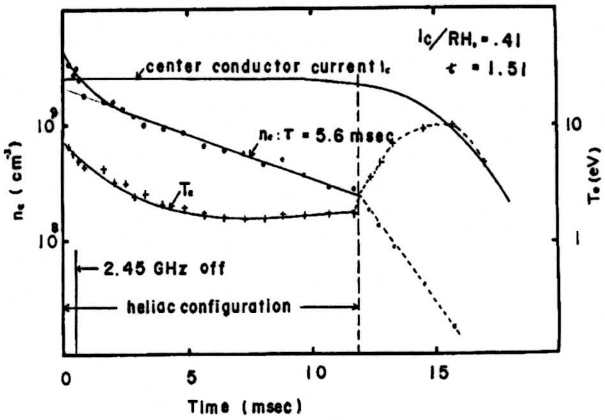

Figure 1

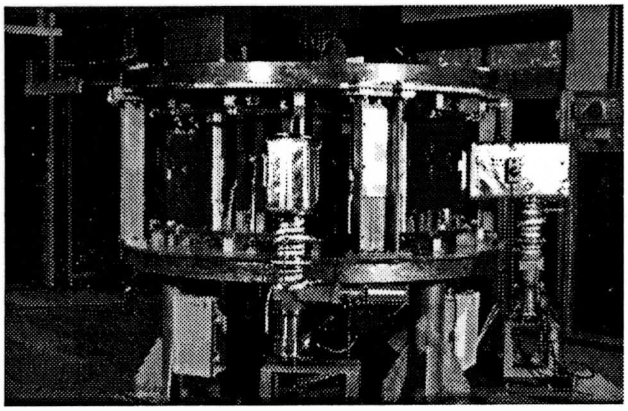

Figure 2: The TU-Heliac

RF Experiments in CHS

Use of the 28-GHz gyrotrons has been temporarily discontinued to upgrade the power supply. In the meantime, experiments on using ICRF plasma production to create a target plasma for neutral injection have been continued using the Nagoya type III antenna originally developed for IBW heating.

The magnetic field strength dependence, gas puff control (timing and duration), wall conditioning including Ti gettering, and the distance between the outermost magnetic surface and the movable antenna all play important roles in obtaining better plasma parameters. A summary follows:

- The electron temperature at the center $T_e(0)$ reaches 200–300 eV when the magnetic field strengths are 0.6 T and 1.1 T for two frequencies studied, 7.5 MHz and 13 MHz, respectively. The average electron density $\bar{n}_e$ is 5–6x10^{12} cm^{-3}. The ion temperature measured tangentially with a time-of-flight neutral particle analyzer is 200–300 eV. Plasma production at higher magnetic field, more favorable for neutral beam injection, will be tried at a higher frequency.
- Precise control of gas fueling and Ti gettering (with coverage of about 10% of the vacuum vessel so far), are important to obtain well qualified plasmas.
- The Faraday shield of the movable antenna must be close to the calculated outermost magnetic surface to obtain a high-T_e plasma. As the distance between the Faraday shield and the outermost flux surface increases, the electron temperature decreases. No further improvement is observed at antenna positions inside the outermost magnetic surface.

Keisuke Matsuoka
Institute of Plasma Physics
Nagoya University, Japan

Status of Stellarator Work at the Kharkov Physical Technical Institute

At the Kharkov Physical Technical Institute the reconstruction of the magnetic system of the URAGAN-3 torsatron is complete. The new magnetic system (URAGAN-3M) includes new l=3, m=9 helical windings and p=4 compensating field windings. The magnetic system was designed for operation at a magnetic field of 2 T and has been tested at a magnetic field of 1.6 T. Magnetic coil alignment studies showed that the magnetic coils are centered to within 1 mm of the design location.

Flux surface studies were performed for URAGAN-3M in joint work with the Institute of Plasma Physics of Stuttgart University. These studies showed that the magnetic configuration in URAGAN-3M was improved. The last magnetic surface had an average radius of 11 cm and a rotational transform, $\iota\!\!\!-(a) = 0.3$.

Power balance and impurity behaviour studies were performed for high-temperature Q-discharges with B = 0.45 T, $\bar{n}_e = 2\times10^{12}$ cm^{-3}, $T_i(0) \leq 1$ keV before URAGAN-3 shut down in May 1988. It was shown that in Q-discharges most of the RF power radiated by the antenna (~90%) goes to create a low-density cold plasma mantle in the whole vacuum chamber (volume = 70 m^3). The RF power absorbed by the plasma (~11 kW) mostly (=10 kW) goes to heat the electrons ($T_e(0) \approx 0.3$ kW) and is lost in equal parts by the electron heat conductivity and radiation. The ion energy losses are mostly charge exchange (≈ 1 kW). Comparison of experimental data with the predictions of theory showed that the ion heat conductivity doesn't contradict the neoclassical value. The electron heat conductivity is close to neoclassical at the plasma center and anomalous

$$[\chi_e \approx \frac{1\times10^{17}}{n_e T_e^{2/3}} \text{ cm}^2 \text{ s}^{-1}] \text{ at the periphery } (r \geq 0.7a).$$

A carbon injection experiment allowed us to estimate the carbon concentration in Q-discharges ($\bar{n}_c \approx 5\times10^{-3}\,\bar{n}_e$) and to conclude that carbon plays a negligible role in radiative losses. An analysis of carbon ion C^{4+} spectral line time history allowed us to estimate the values of the diffusion coefficient ($D \approx 1.4\times10^4 \text{cm}^2\text{s}^{-1}$) and the inward flow velocity ($v \approx 3.5\times10^3 \text{cm s}^{-1}$).

URAGAN-2M project

In December 1988 a flywheel AC generator (P = 200 MW, W = 0. 8 GJ) for the URAGAN-2M power supply was assembled. Seven of 16 toroidal field coils, one poloidal field coil (of eight) and supporting rings have been delivered to the laboratory. The remaining toroidal and poloidal coils and the vacuum chamber will be delivered by September 1989. The assembly of device (without helical coils) is planned for December 1989. The helical coil construction is proceeding as scheduled, with delivery in June 1990.

Oleg S. Pavlichenko
Kharkov Physical Technical Institute
Akademicheskaya Street
Kharkov 310108, USSR

Preliminary Assessment of the Effects of Field Error Correction in ATF

At the International Stellarator Workshop in Oak Ridge, we reported a preliminary assessment of the effects of the field error correction on plasma properties. In this report, we compare plasma characteristics before and after the correction in terms of configuration scan results, electron temperature profiles, and global confinement times, and then discuss the near-term program direction.

The field error correction has widened the operational range of the vacuum axis position (Figure 1), which is an important parameter for control of the magnetic well or hill of the configuration. Before the buswork modifications, an outward shift of the vacuum axis led to poor plasma performance (sharply reduced W_p and $\bar{n}_e$) due to the presence of growing *q*=2 islands. After the correction, an outward shift produces improved performance for both ECH and NB-heated plasmas.

ORNL-DWG 89M-2441 FED

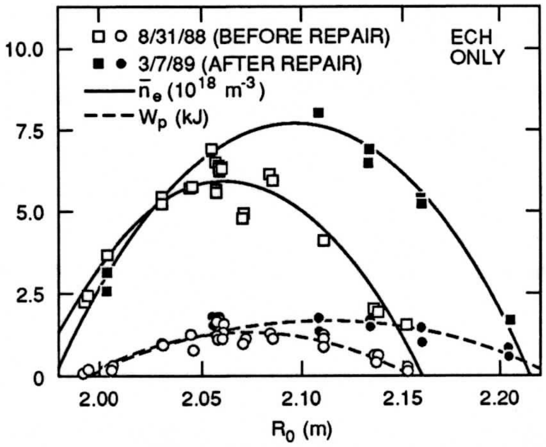

Figure 1: ATF profiles before and after error correction

Electron temperature profiles appear to be broader following the field error correction. Although the electron temperature at the outer radii (r/a < 0.5) is only marginally higher, when normalized to the central temperature, the T_e profile is broader than before the correction. Density profiles also tend to be broader after correction and in some cases they are slightly hollow. Profile analysis for a typical case with 0.7 MW unbalanced injection shows $\beta_0/\langle\beta\rangle$= 3–4, which may be compared with $\beta_0/\langle\beta\rangle$ = 5–7 before the correction.

Values of stored energy from diamagnetic measurements are comparable to those predicted by the "LHS" scaling,

$$\tau(\mathrm{LHS}) = 0.17{*}P^{-0.58}n^{0.69}B^{0.84}a^{2}R^{0.75}$$
$$[\mathrm{s};\quad \mathrm{MW},\ 10^{20}\mathrm{m}^{-3},\mathrm{T},\quad \mathrm{m,m}],$$

with the full plasma radius a=0.27 m used in the scaling law. Global confinement data so far have not shown improvement due to the field error correction. These results may be a mere reflection of lack of optimization due to limited experimental time. The maximum $\bar{n}_e$ values achieved so far after the correction, have not been as high as before, and balanced beam injection has not yet been explored. Although radiative loss is qualitatively similar, a detailed comparison of the spectroscopic data before and after the correction has not been made.

Although a preliminary assessment of the effects of the field error correction has been made for the plasmas presently available, the plasma quality in the new configuration needs improvement. We expect to improve our understanding of these effects as we proceed with the planned program and to return to experimental conditions comparable to those obtained before the correction. Meanwhile, the near-term program emphasis is first to improve plasma performance (i.e., to achieve higher stored energy) with: (a) operation at 2 T; (b) pellet injection; (c) improved cleanliness with additional getter sources; and (d) the use of the mid VF coil for more flexible configuration control. Equally important is development of fluctuation diagnostics for transport/fluctuation studies, e.g., the reciprocating Langmuir probe (in collaboration with the TEXT Group) and the reflectometer (with the TJ-II Group and Georgia Tech).

ATF Group (compiled by M. Murakami)
Oak Ridge National Laboratory
P.O. Box 2009 Oak Ridge, TN 37831, USA

People

In January 1988, Oleg Pavlichenko was elected the Director of the Plasma Physics Division and nominated the Assosiate Director for Plasma Fusion of the Kharkov Physical Technical Institute. Before this election, he was the Stellarator Experiment Division Head.

Evgeny Volkov was elected the Stellarator Experiment Division Head in October 1988. Previously, he took part in experiments on the SIRIUS stellarator, the *l* = 1 torsaton VINT-20, and the modular torsatron URAGAN-5.