MEETING REPORT

SUMMARY OF THE EIGHTH TOPICAL CONFERENCE ON RADIO-FREQUENCY POWER IN PLASMAS, IRVINE, CALIFORNIA, MAY 1–3, 1989

INTRODUCTION

The Eighth Topical Conference on Radio-Frequency (rf) Power in Plasmas was held at the Irvine Hilton from May 1–3, 1989. The biennial conference was hosted by the University of California–Irvine. Eleven invited talks and 113 contributed posters were presented. Scientists attended from a variety of institutions with ~40% of the conference participants coming from U.S. Department of Energy-funded laboratories, 30% from U.S. universities, 30% from institutions in Canada, Europe, and Japan, and a few scientists from industry. As usual, fusion applications of rf dominated the conference. Papers were presented on all of the major rf heating and current-drive methods for fusion plasmas, including ion cyclotron range of frequencies (ICRF), lower hybrid, electron cyclotron wave heating (ECH) and ion Bernstein wave (IBW) as well as applied rf technology and wave theory. There were no parallel sessions, and the poster sessions were not arranged by specialized subtopics, making for a less hurried atmosphere where one could get a broader picture of the rf field.

The meeting began with an overview of the role of rf waves in tokamak research given by P. Rutherford of Princeton Plasma Physics Laboratory (PPPL). He pointed out that bulk heating of tokamaks with rf is generally accepted by the fusion community as being comparable to neutral beams. The challenge now is to use the unique features of rf to improve on tokamak performance. Examples cited include the use of central ICRF heating in conjunction with central fueling to enhance confinement such as the Joint European Torus (JET) ICRF-pellet experiments, the use of lower hybrid current drive (LHCD) to gain access to the second stability regime such as proposed for the modified Princeton Beta Experiment (PBX-M), and the use of ECH to suppress locally unstable modes such as the suppression of edge localized modes on the DIII-D tokamak.

ION CYCLOTRON WAVES

Ion cyclotron heating continues to be the largest rf subfield with active experiments on the JET, JT-60, Tokamak Fusion Test Reactor (TFTR), Axially Symmetric Divertor Experiment (ASDEX), and Tokamak Experiment for Technology Oriented Research (TEXTOR) tokamaks; the Phaedrus-B tandem mirror; and the planned ICRF experiments for the Advanced Toroidal Facility (ATF) Stellarator and Compact Ignition Tokamak (CIT). D. Start of JET Joint Undertaking, United Kingdom, reported a number of impressive high-power results from JET, including the ICRF heating of pellet fueled discharges that improved energy confinement by a factor of 2 over L-mode, combining ICRF with neutral beams to produce an 11-MJ, double-X-point plasma, and modulating the ICRF to determine central heat transport coefficients. Significant advances in ICRF technology were also made by the JET team, including operation at 6 MW for 20 s into a plasma, use of automatic antenna matching by frequency control, and plans for beryllium Faraday screens. The JT-60 team showed ICRF heating at the second, third, and fourth harmonics and reported that their best heating results occurred for conditions where $\bar{n}_e > 3 \times 10^{13}$ cm^{-3} and $I_p >$ 1.5 MA. Recent ICRF experimentation on JT-60 has been slowed by the installation of a bottom X-point configuration with the plasma edge located far from the antenna. Initial ICRF results on TFTR reported by P. Colestock of PPPL showed good correlation between theory and experiment for the toroidal-mode structure and for sawtooth mixing of the fast ion tail. Efficient electron heating and low impurity production for out-of-phase operation of the ICRF antenna were also observed on TFTR.

D. Ehst of Argonne National Laboratory pointed to the significant cost and technological advantages of fast wave current drive (FWCD) over neutral beams if FWCD can be experimentally demonstrated. Negative ion neutral beams operating at 1 to 2 MeV are presently the leading contender for central current drive on International Thermonuclear Experimental Reactor (ITER) because of the simpler theory of beam current drive. However, since all of the options for central current drive on ITER lack a demonstration of technology or plasma experimental results, or both, there appears to be plenty of opportunity for rf methods to influence the design. In the past, FWCD experiments in the lower hybrid range of frequencies have given null results for densities above the lower hybrid density limit. An encouraging report by H. Kawashima of the Japan Atomic Energy Research Institute (JAERI) showed significant electron damping occurring for high-$k_\parallel$, 200-MHz fast waves in ECH heated target plasmas on the JFT-2M tokamak. R. McWilliams of the University of California–Irvine showed FWCD for densities above the lower hybrid density limit for a range of frequencies in the Irvine torus. R. Taylor of the University of California–Los Angeles reported much improved high-power operation of the fast wave antenna on Continuous Current Tokamak using an enclosed antenna design. A 2-MW FWCD experiment in the ICRF is planned for the DIII-D tokamak.

LOWER HYBRID WAVES

Improvements in the experimental efficiency of LHCD continue to be made on JT-60 and ASDEX through improvements in the launched wave spectrum. K. Uehara of JAERI reported a current-drive figure of merit (FOM) in the range needed for ITER ($I\bar{n}_e R/P > 0.3$) as well as the successful operation of a 24-waveguide multijunction grill on JT-60. Another significant result from the JT-60 experiment was the demonstration of off-axis wave damping controlled by phasing the grill. Evidence from hard X-rays on JT-60 showed that waves having $n_\parallel \approx 2.75$ produced a slightly hollow rf current profile peaking toward the plasma edge, while waves having lower $n_\parallel$ produced rf current peaking in the plasma center. F. Leuterer of the Max-Planck-Institut für Plasmaphysik (MP-IPP), Federal Republic of Germany, showed an improved current drive FOM with a 24-waveguide grill on ASDEX. Current profile control experiments are planned for JET and PBX in the near future. Use of LHCD to achieve second stability tokamak operation was reported by the Versator group at the Massachusetts Institute of Technology (MIT), and wave damping-profile calculations were carried out by several researchers for present and future devices. Current rampup and transformer recharge by LHCD were discussed in connection with plans for the Varennes tokamak (Centre Canadien de Fusion Magnétique). A commonly accepted notion about lower hybrid waves has been that the damping was too strong to allow penetration to the center of a reactor-type plasma. R. Cohen of Lawrence Livermore National Laboratory (LLNL) presented a theory for pulsed LHCD that may get around the problem of strong damping at the plasma edge and allow lower hybrid wave penetration into the center of very hot plasmas such as ITER.

ELECTRON CYCLOTRON WAVES

Experimental work in the ECH area is increasing substantially now that high-power tubes are becoming available in that frequency range. There is hope that localized heating from ECH can be utilized to improve tokamak performance. R. Prater of GA Technologies and K. Hoshino of JAERI presented results from the DIII-D and JFT-2M tokamaks, where H-modes were produced by ECH alone. However, global energy confinement during ECH on DIII-D and T-10 appeared to follow the L-mode trend of confinement degradation with increasing power, which is observed with other supplementary heating methods. V. Erckmann of MP-IPP presented evidence that ECH experiments agreed with ray tracing calculations and described different modes of operation of the Wendelstein-VII-AS stellarator with ECH. B. Lloyd of Culham Laboratory, United Kingdom, and Y. Terumichi of University of Kyoto showed evidence for the existence of electron cyclotron current drive in small tokamaks. Several people reported on calculations of electron cyclotron wave current drive for future devices such as CIT, Next European Torus, and ITER. Energy and particle transport studies during ECH were reported from the Fusion Research Center at the University of Texas-Austin (TEXT) tokamak. The Microwave Tokamak Experiment (MTX) team from LLNL described their plans for ECH at 140 GHz using a pulsed free electron laser source.

OTHER rf WAVE METHODS

Ion Bernstein waves have the potential attraction of a convenient launching scheme in the ICRF. Recent results reported from the DIII-D and JFT-2M tokamaks have as yet unexplained features in the wave coupling, plasma density increase, and impurity production. An IBW experiment using waveguides is planned for the Frascati Tokamak-Upgrade at Frascati, and an IBW experiment for local plasma pressure control is planned for PBX. Alfvén wave calculations were described by several researchers.

Reports on several nontokamak rf experiments were presented. I. J. Donnelly of the University of Sydney discussed current drive in a rotating magnetic field device. S. Savas of Applied Materials reported on probe measurements of rf-generated plasmas used for plasma materials processing, and R. Motley of PPPL discussed an rf source for an oxygen beam.

ANTENNA TECHNOLOGY

The evolution toward larger machine size and higher powers has led to the need for better understanding of antenna technology, especially in the area of ICRF, where the problem is more difficult analytically and where the higher powers of present-day experiments provide more possibility for antenna/plasma interaction. Changes in plasma edge conditions for various modes of operation (limiter, divertor, H-mode, etc.) further complicate our understanding. A number of researchers studied the antenna problem using numerical simulations. Experimental measurements of antennas were reported by N. Hershkowitz of the University of Wisconsin using the Phaedrus-B device and at Oak Ridge National Laboratory using their rf test facility. Analytical and numerical modeling results were also reported by both groups as well as the Alcator-C Mod tokamak group from MIT.

CONCLUSION

Steady experimental and theoretical progress has been made since the last meeting in many of the rf heating and current-drive areas. Because the field of rf/plasma interactions is maturing, recent progress has come through incremental improvements in the understanding of rf applications rather than through sweeping breakthroughs. In the fusion area, it is becoming clear that simple bulk heating is not enough and that further control of the plasma may be needed in order to improve confinement. The wide variety of rf methods and capabilities offers many possibilities to enhance the confinement of fusion plasmas, perhaps through local heating or local current drive or production of anisotropic particle distributions. Ongoing experiments throughout the world promise continued progress by the next meeting.

The contributed and invited papers will be published as four- and eight-page papers in the conference proceedings. Inquiries about the proceedings can be addressed to Series Editor, AIP Conference Proceedings, American Institute of Physics, 335 E. 45th Street, New York, New York 10017. Oak Ridge National Laboratory will host the next conference in 1991.

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