RESULTS AND UPDATE ON THE TdeV FACILITY

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It is the purpose of TdeV to contribute significantly to a certain number of selected areas in Tokamak physics, and thereby enable the Centre canadien de fusion magnétique to participate in international fusion research. This goal is seen in the context of size and budget limitations.

TdeV is a device of modest size operating at 1.5 Tesla. In divertor mode with a= 0.27 m and R=0.87 m, the plasma current attains 300 kA. Im ohmic operation, the device is capable of electron densities of about 6 10^{19} m^{-3} and electron temperatures of 1 keV. A major feature of the device is it capacity for long pulse operation using lower hybrid current drive. This feature will be used to particular advantage in long pulse studies of recycling, impurity accumulation, and material erosion and shock.

The double-null three-coil divertor system is a major tool opening the path to a number of edge plasma and impurity control and accumulation studies. The divertor plates are also electrically insulated and equipped with current feeds, and can therefore be used for biasing, vertical current injection, and helicity injection experiments.

The addition of a lower hybrid current drive system in 1993 will enhance the capacity of the device. Long pulses, higher plasma parameters, and the study of enhanced confinement modes will then become possible, as will direct studies of the current drive physics. The parameters of the device can be further enhanced by the subsequent installation of additional heating.

A complete set of diagnostics for detailed profile measurements of the central plasma, as well as impurity and edge plasma measurements, are either operational or will be added in the future.

MAIN RESEARCH AREAS AND EXPERIMENTAL RESULTS

The particular areas of study are divertor and edge plasma physics, impurity transport, sources, and control, plasma-wall interaction and materials studies, transport and equilibrium of the central plasma. In the course of the program, these areas will be studied with particular emphasis on long pulses, current drive, additional heating and the associated enhanced confinement regimes.

Divertor and edge plasma studies

Divertor and edge physics, a very important topic for large machines and fusion reactors, is a domain particularly suited for study in a medium sized device because the edge parameters can be similar.

Measurements with specially designed Langmuir probe arrays and sophisticated spectroscopic techniques in the visible have permitted the spatial resolution of drift velocities of certain light impurities. Such velocities are in both the toroidal and the poloidal directions, and are associated with the biasing, both natural (ambipolar) and imposed (via the divertor plates), of the plasma. Most theories of improved confinement postulate the existence of such drifts, which are important as well for sweeping impurities into the divertors.

During divertor biasing experiments, important changes in the edge electron density and temperature have been measured by spectroscopy on a carbon-lithium beam ablated by laser into the edge plasma and even penetrating a little past the last closed flux surface into the main plasma.

Evidence that energy confinement in the outer regions of the central plasma may be improved by biasing (of both signs) is the suppression of electrostatic density fluctuations, as measure by CO2 laser scattering. Preliminary data on intrinsic and injected impurities indicates that biasing does in fact improve impurity removal from the plasma.

Impurity transport, sources, and control

TdeV can provide unique contributions to this area by directed experiments to measure and control impurities using the combination of pumped closed divertor plates and limiters, impurity injection experiments and its complement of impurity diagnostics.

Results show that impurity transport is anomalous, as in other similarly sized machines. Preliminary work shows that impurity transport changes when the plasma is biased via the divertor plates. Impurities do not appear to accumulate in the main plasma, and the divertors are effective in removing light impurities, since increases in partial pressure in the divertor boxes, enhanced by appropriate biasing are observed. Boronization reduces the plasma oxygen content by an order of magnitude, but has little effect on carbon.

Bolometry reveals that TdeV normal discharges in the divertor mode radiate about 30% fo the ohmic input power. This figure can fall by over a factor of two when the vessel is boronized, depending on the method. Negative plasma biasing reduces the radiated power by as much as 25%, whereas positive biasing increases radiative losses.

Plasma wall interaction and material studies

Hydrogen recycling and transport as well as erosion and redeposition of limiter and divertor plate materials are important topics for large machines and can be studied in TdeV

An extensive wall conditioning program has been undertaken to boronize TdeV. A thin boron layer on the side of the vacuum vassel not only presents a low Z surface to the plasma, but also reduces the oxygen content in the vessel by chemical gettering. Three boronization techniques have been tested and evaluated.

The first technique uses a boron-graphite hemispherical limiter head mounted on the test limiter which when lowered in to the edge of the hot plasma, heats up and evaporates boron (and carbon). Results indicate that this technique effectively reduces the oxygen contamination of the plasma by a few tens of percent, but is short lived. The effect dissapears after 6-10 shots. Boron-graphite appears, however, to be an interesting first wall material, and, in addition, some evidence of reduced carbon sputtering has been found during the tests.

The second boronization technique involves using TMB (trimethylboron) as a fuelling gas. This technique seems to give results similar to the previous technique: plasma parameters are improved by about the same amount, but the effect is short lived. The additional carbon in the TMB molecules does not seem to be detrimental.

The third and more conventional technique is to form a boron layer by plasma enhanced chemical vapour deposition fo TMB. This technique improves plasma parameters (ie. reduces the oxygen impurity) more than the other two techniques and last for hundreds shots. High density plasmas (up to $6\ 10^{19}\ m^{-3}$) can be obtained when TdeV is boronized in this manner.

Transport and equilibrium of the main plasma

The topics in this area are chosen for their interest to larger devices in areas in which the diagnostics are particularly appropriate (e.g. perturbational transport measurements, sawteeth, current transport, turbulence) or in which the device is equipped to make a unique contribution (e.g. fast plasma current rampdown, vertical current injection).

Experiments on fast current rampdown are continuing. Disruption free rampdown rates up to about 16 MA/s down to currents of only a few tens of kA can be achieved by gas puffing at the end of the current plateau. We speculate that the gas puff increases the resistivity allowing faster current density redistribution and tending to stabilize MHD disruptive modes.

Studies have begun and will be continued on vertical current injection using the insulated divertor plates to determine the effect on the plasma horizontal position control. Helicity injection, which will require emitting plates, may be a future field of study in this area.

Current drive and supplementary heating

While providing long pulses and additional heating, the current drive system of Tdev will contribute to research in this field, particularly in the area of current transport and synergistic effects. access to enhanced confinement modes would render the studies in the other research areas more relevant.

Several current drive scenarios are under consideration. In addition to the long pulse condition entirely with RF current drive, an alternating cycle of current drive-enhanced ohmic operation (5 s) with low density transformer recharge (5 s), will be examined. The RF-ohmic part of the cycle will permit higher density operation than pure RF current drive, while the recharge part will allow investigation of limits to the recharge speed.

Plama heating accompanying the current drive is expected to be significant, doubling the electron temperature. Attainment of the enhancement confinement H-mode is expected, even without plasma biasing. Control of the electron density profile in the SOL just in front of the RF antennas using plasma biasing should enable optimum coupling to the plasma of the RF energy. Clearly, the attainment of higher temperatures, better confinement and longer pulses during RF current drive will enhance the studies described in the other sections of this program.

Theory and interpretation program

The main objective of the theory and interpretation group is the support and giudance of experimental tokamak research at CCFM by means of applied theory. The program of the group is therefore strongly coupled to the main topics of the experimental program described previously and consists mainly of data interpretation and numerical simulation.

STATUS AND PLANNING

The scientific program is and will be implemented in several phases.

Phase 1

This was the initial operation phase with limiter plasmas, terminated in Dec 1988. The major goals were:

- commissioning of the device and some diagnostics
- commissioning of cleaning systems
- measurements of the main plasma parameters with power balance
- measurement of plasma-wall interaction

- determination of operational limits in current and density
- study of fast plasma current rampdown, using EF position control
- tests of TiC coatings
- technical test of multi-pulse operation
- test of impurity injection

Assembly I-II

This assembly phase started at the beginning of 1989. Diagnostics, outer TF coil legs, upper PF coils and structures, and the vacuum vessel were dissambled. The internal coils and liner were installed and the device reassembled. The HP power supply for fast position control was installed. Most of the diagnostics were modified and quite a few were added. The device and the diagnostics were recommissioned. The vacuum vessel was closed in the late spring of 1990, and , by the fall diverted tokamak discharges of excellent quality were being routinely obtained.

Phase IIa

This phase is called the biased divertor phase and includes several aspects of divertor operation with rapid horizontal position control using the internal coils. A single short plasma pulse is produced. Work is currently being carried out on the following topics:

- divertor plate biasing, effects on confinement and transport, impurity levels, turbulence
- evaluation of boronization techniques
- single null divertor operation
- current injection via divertor plates
- operation with deuterium, effects on confinement and transport, impurity levels and divertor operation
- test limiter- further tests with boronized graphite and TiC
- laser ablation to measure impurity transport, divertor efficiency, scapeoff layer parameters
- gas injection to measure impurity gas- scrapeoff layer screening, divertor pumping, transport, divertor efficiency
- evaluation of divertor pumping with one unit

Openings between phases IIa and IIb

In 1992, 3 machine openings will be performed for a total of about 3 months for the following operations: narrowing of the divertor throat, installation of the prototype cryosorption pump, installation of a reversing "switch" for the toroidal magnetic field, and improvement of the voltage standoff of the divertor plates. The highly encouraging results from plasma biasing experiments resulted in the decision to delay the installation of the 3 additional cryosorption pumps until a few months before the opening for the RF antenna. In the autumn of 1992, these pumps will be installed in the upper divertor chamber. At the same time, installation is planned for the thallium atom beam diagnostic for the compact torus injector at the request of the collaborators who are constructing it.

Phase IIb

Machine operation will probably become routine. In addition to the continuation of the experiments of phase IIa, the following topics will be studied:

- plasma biasing using test limiter and trials using a LaB6 head
- evaluation of divertor pumping with 4 cryogenics units
- lithium pellet injection experiments

Opening between phases IIb and IIIa

During this opening the Lower Hybrid Current Drive system (LHCD) will be installed. It is also hoped to install a diagnostic hydrogen atomic beam, some special diagnostics for the LHCD system and a emissive electrode. Depending on the results in Phase IIb we might install additional divertor pumping units.

Phase IIIa

This phase represents the beginning of the experiment using the LHCD system. In particular it is envisaged to pursue the following topics:

- LHCD and OH operation scenarios (maximum 5 s)
- LHCD characterization with new hard and EC transmission diagnostics
- OH transformer recharge
- helicity injection via emissive electrode
- improved confinement regimes with LHCD
  - current profile control
  - transport and impurity accumulation
  - turbulent heating and current density perturbations
  - divertor plate biasing
- composite carbon and other new materials on the test limiter
- edge plasma and SOL studies with thallium atom beam
- light impurity density and transport measurements with diagnostic light element beam
- helium injection using diagnostic beam and studies of fusion ash transport and divertor pumping
- characterization of pumped divertor boxes
- compact torus fuelling experiments
- continued transport and confinement experiments using gas puffing, laser ablation and pellet injection with different current density profiles (LHCD), divertor plate biasing and wall conditioning

Opening between phases IIIa and IIIb

This opening is planned for preparation for longer pulse operation of TdeV by modification of some cooling systems, RF antenna etc...

Phase IIIb

During phase IIIb, the following are the topics that are planned to be addressed:

- long pulse (30 s) LHCD and OH operation
- divertor operation under high plate loading - characteristics under different conditions
- density profile peaking and fuelling with deuterium and Hydrogen ice pellet injection, possibly multi-pellet

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