THE BRAZILIAN SPHERICAL TOKAMAK EXPERIMENT

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Abstract: This paper gives a brief description of the operating parameters, scientific program and design of the small spherical tokamak ETE, presently under construction.

The small spherical tokamak ETE (Experimento Tokamak Esférico) is presently being built at the Plasma Laboratory of the National Institute for Space Research (LAP/INPE) in Brazil. It will be devoted to the study of operating regimes, confinement properties and current drive schemes in a low-aspect-ratio plasma configuration. ETE is a reduced, less expensive version of previous designs [1][2] which maintains the attractive characteristics of low-aspect-ratio tokamaks as compact thermonuclear reactors and neutron sources. A wealth of new physics remains to be explored in such a configuration, allowing to perform, even in a modest device, a research program with possibly important contributions to the international fusion research effort.

ETE principal parameters are listed in Table 1. The initial phase parameters can be attained with fully inductive current drive using the capacitor banks presently available for the ohmic and toroidal field circuits, but the extended phase operation depends on an upgrade of the capacitor banks. The initial operation will be devoted to produce a modestly high plasma current $I_T(a) \cong 220\,\mathrm{kA}$ ($\sim 15\,\mathrm{ms}$) in a 1.5 aspect-ratio configuration with a toroidal field $B_0 \leq 0.4\,\mathrm{T}$ ($\sim 100\,\mathrm{ms}$), and to explore the low-q operating regime limits. In the extended phase one expects to achieve high β operation, near the Troyon limit, with plasmas of lower collisionality and more reactor relevant parameters. One expects also to increase the pulse length to values that will permit a better study of the plasma confinement properties. In this extended phase various non-inductive current drive methods will be considered for implementation, such as helicity injection, internal pressure driven currents and fast magnetosonic/Alfvén-wave absorption. Since the present design allows space for

Phase	Initial operation	Extended operation
Major radius $R_0(a)$	0.30 m	0.30 m
Minor radius a	0.20 m	0.20 m
Elongation κ	1.5	1.7
Triangularity δ	0.2	0.3
Toroidal magnetic induction B_0	0.4 T	$\leq$ 0.8 T
Toroidal plasma current $I_T(a)$	220 kA	440 kA

Table 1: The ETE principal parameters.

installation of a simple divertor chamber, electrostatic helicity injection by means of polarized divertor plates will be one of the current drive schemes strongly considered for ETE.

The design of ETE components was kept as simple as possible. Figure 1 shows a general view of the tokamak. The total height of the device is about 2.6 m and the diameter is 1.8 m. The toroidal field (TF) magnet uses a D-shaped minimum stress design which incorporates innovative single bolt joints and a system of stray magnetic field compensated current feed rings. Each of the 12 TF coils will be built as a single turn and is free to expand in the poloidal plane, leading to an extremely light design. Since the current density is constant over the coil, each turn must be water cooled between shots in its entire length. The uniform heating of the coil should reduce the end effects due to temperature variations.

The ohmic heating solenoid (OH) has to fit in the narrow gap between the outer radius of the TF central column and the inner wall of the vacuum vessel. In ETE the OH solenoid will be formed by two layers of a square cross-section, water cooled hollow conductor and will be wound around the central column of the TF magnet. The solenoid is capable of providing a 0.28 Wb flux variation with double swing operation within the admissible stress limit for half-hard annealed copper. In the initial phase the solenoid will be driven to about half its maximum flux swing capability. In the extended phase the solenoid operation will be limited by the maximum adiabatic temperature rise during each shot. Two pairs of passive compensation coils have their location and number of windings optimized to produce, together with the OH solenoid, a minimum error field over a large region near the midplane of the plasma (hexapole field cancelation). These coils must also be water cooled since they are fabricated with the same conductor used in the OH solenoid and are in series with it. The remaining two pairs of poloidal field (PF) coils supply the time-varying vertical field necessary for plasma position control and for some limited control of the plasma elongation. The location of all the PF coils was carefully studied to allow good diagnostic access.

The vacuum vessel is being constructed from thin-walled inconel alloy. There is no toroidal break in the vessel and the relatively high resistivity of inconel will help to reduce eddy-current effects. The inner and outer cylindrical walls are manufactured from 1 mm and 6.35 mm thick plates, respectively. The top and bottom parts of the vessel are made from 6.35 mm thick standard sized torispherical heads. Standard ConFlat flanges are used so that adequate baking and discharge cleaning at high wall temperature can be implemented. A $1500\,\ell/s$ turbomolecular pump backed by an oil filled rotary pump will be installed. Several fixtures inside the vacuum vessel will provide support for the rail limiters and diagnostics. If a non-inductive start-up and current drive method proves effective in the future, the inner cylindrical wall can be removed by grinding and replaced by a smaller diameter tube. Without the OH solenoid, the aspect-ratio can be reduced from 3/2 to 4/3.

The support structure consists basically of two crowns and two rings of insulating material placed symmetrically with respect to the midplane of the device. The TF coils will be inserted in slots cut in the crowns and rings, which leave the coils free to move in the poloidal plane but resist the out of plane forces. A collection of stainless steel rods connects the crowns and rings, forming a rigid truss structure. The PF coils will be attached to the crowns and rings by simple L-shaped supports and clamps which allow some control of the coils position. The vacuum vessel will be placed on insulated shock absorbers attached to the support legs and to the lower ring. The entire assembly is modular an allows very good access for diagnostics. Simple engineering calculations show that the structure is capable to resist the normal and fault electromagnetic loads [3], but a more careful analysis is necessary to access the operating limits of the TF coil ($B_0 \leq 0.8\,\mathrm{T}$) and the structural response of the vacuum vessel to the dynamic forces during a plasma disruption.

The diagnostics planned for the first phase of operation of ETE comprise a minimum set necessary for control and measurement of the principal plasma parameters. Table 2 lists the

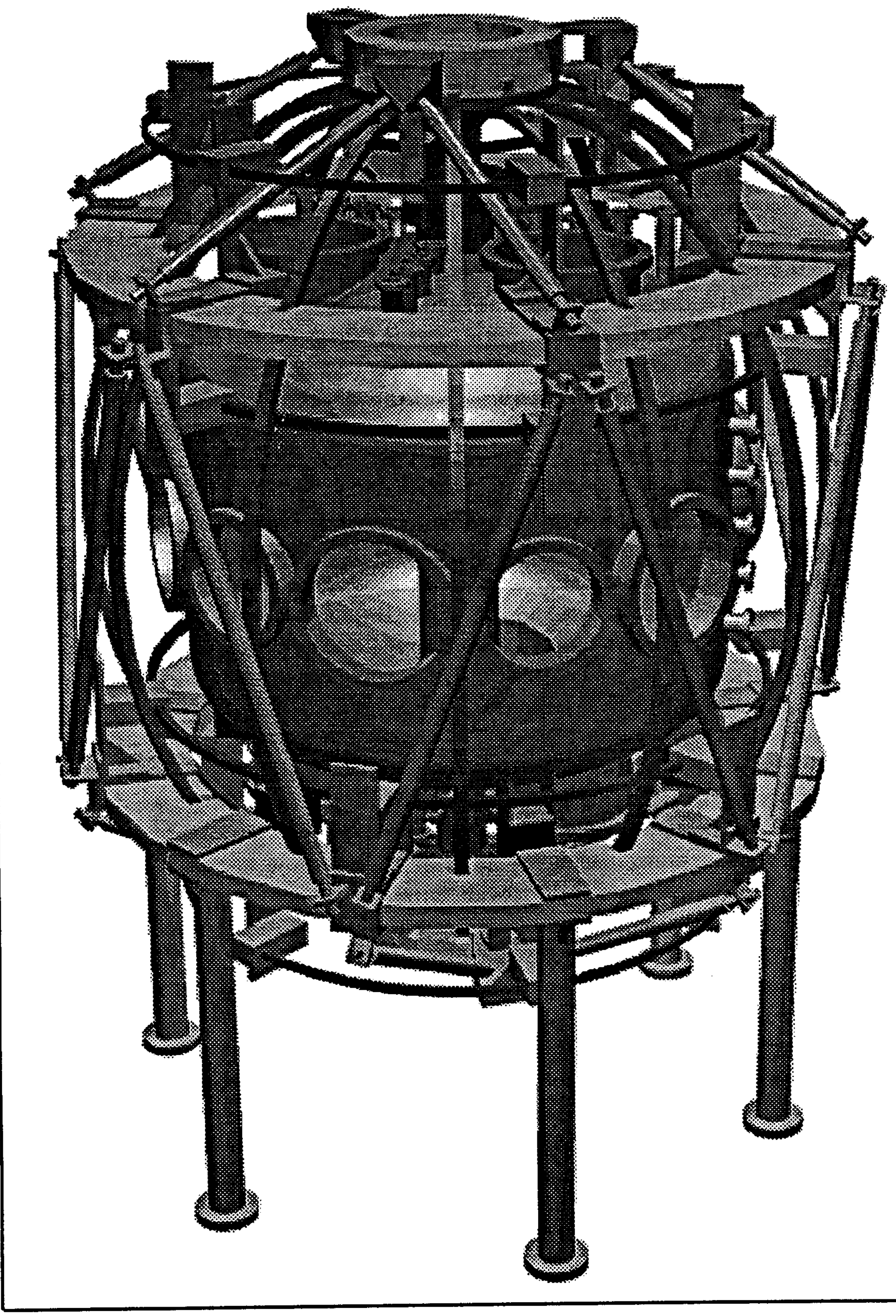

Figure 1: Perspective view of the ETE spherical tokamak.

Diagnostic	Plasma Parameters
Magnetics	Magnetic reconstruction
Bolometers	Radiated power
Hard X-ray monitors and soft X-ray diodes	Fast electrons, magnetic activity and electron temperature
Microwave interferometer	Integrated density
Optical and VUV spectrometers	Electron temperature and impurities
Electrostatic probes	Plasma edge parameters
Low-energy lithium beam	Plasma edge parameters
Thomson scattering	Electron temperature and density profiles

Table 2: Diagnostics in the initial phase of operation of ETE.

diagnostics proposed for implementation during the initial phase, together with the plasma parameters to be measured. The low-energy (10 kV) lithium beam diagnostic is presently under development at LAP/INPE and should be useful for measuring several parameters in the outer region of the plasma, notably the poloidal field profile. Installation of the Thomson scattering system will depend on adequate funding at the time. The data acquisition system will be based on VME modules writing each shot data to dedicated PCs linked via Ethernet to an Alpha server, where an archive shot file can be accessed by users.

References

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