The ETE spherical tokamak: present status of construction

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Abstract

This paper describes the design parameters and the present status of construction of ETE (**E**xperimento **T**okamak **E**sférico), a low aspect ratio tokamak under development at LAP/INPE.

1. Introduction

After the theoretical work of Peng and Strickler in 1986 [1], and more recently after the encouraging results which have been obtained in the START tokamak in operation at Culham/UK since 1991 [2], there is an increasing interest in the experimental behavior of fusion relevant plasmas produced in tokamaks with very low aspect ratio (A = R/a), also named Spherical Tokamaks. Several machines have been proposed in order to investigate the claimed advantages of such geometry. The Plasma Laboratory of INPE has been involved with spherical tokamaks since 1987 when the design of ETA (Advanced Tokamak Experiment) was initiated. The plasma current in this spherical tokamak with A = 1.5 was fully RF driven (no ohmic heating solenoid) [3]. Lather, this project was replaced by the Proto-ETA tokamak [4], a more realistic design which was extensively discussed in two specific Brazil/USA workshops. The ETE spherical tokamak [5] is a scaled down version of the Proto-ETA design, but still keeping parameters allowing the investigation of fusion relevant plasmas with low aspect ratio.

2. Principal components of the machine

The main parameters of ETE are presented in Table 1. In the initial operation phase the plasma current is limited by the energy of the capacitor banks available. In the extended operation phase the fields and the plasma current are limited by the mechanical strength of the coil materials and connections.

	Initial phase	Extended phase
Major radius	0.3 m	0.3 m
Minor radius	0.2 m	0.2 m
Plasma current	220 kA	440 kA
Aspect ratio	1.5	1.5
Elongation	1.6	1.8
Triangularity	0.3	0.3
Toroidal field	0.4 T	0.8 T

Table 1. Main parameters of ETE

The vacuum vessel (figure 1) is being manufactured from Inconel 625, a nickel alloy with high electrical resistivity to diminish induced currents, since there is no electrical break in the toroidal direction.

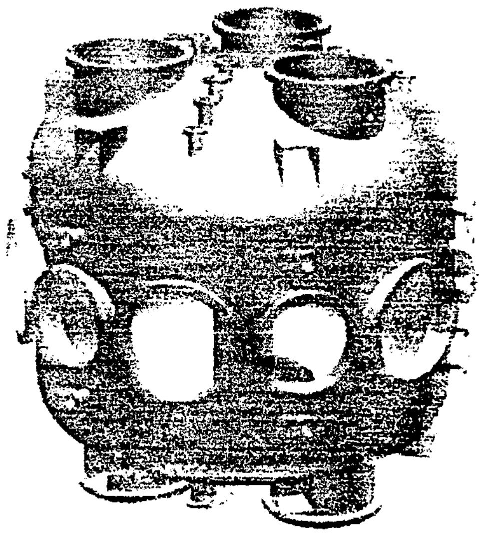

Figure 1. 3D view of the vacuum vessel

The upper and lower domes are made from 6.4 mm thick standard torispherical heads with a diameter of 48". The outer cylindrical wall has an external diameter of 1.2 m and is made from a 4.8 mm thick rolled plate. The inner wall has an overall diameter of 0.18 m and a length of 1.2 m. This internal tube is manufactured from a 1 mm thick rolled plate and incorporates (with no welding) two rigid bellows at the ends for proper interface with the torispherical heads. A total of 58 conflat-standard ports (12xCF14", 4xCF250 and 42xCF40) are available. Presently, the vessel is being assembled in the industry.

The toroidal field coils system (figure 2) will be manufactured from half-hard annealed electrolytic copper and comprises 12 single turn D-shaped minimum stress configuration coils. The coils are connected in series by double stray field compensation rings at the top and bottom of the coils. The conduction area of the conductor is kept constant (~7.34 cm^2). Two transition pieces are used to connect the central trapezoidal conductor to the external rectangular conductor. These pieces will be electron beam welded to the central conductor and the top one incorporates a single demountable bolt joint that allows the insertion of the vacuum vessel. The coils are water cooled by copper tubes soft-welded to the conductors. The height of the coils is 1.68m and the overall diameter is 1.64 m. The coils were designed to produced a maximum toroidal magnetic field of 0.8 T at the center of the plasma column, with a ripple of less than 0.3%. Presently, the copper bars are being purchased and the mechanical tests of the bolt joint and welding are in progress.

The poloidal field coils system, schematically shown in figure 3, is composed of the magnetizing coils (solenoid + compensation), equilibrium (or vertical) field coils and elongation coils.

All poloidal field coils will be manufactured in our laboratory from a hollow copper conductor with square cross section (9x9 mm). A simple winding machine was constructed and tested to manufacture the solenoid and the other coils. The conductor insulation will be made during the winding process with two layers of poliamide-amide adhesive tape plus two layers of fiber-glass cloth adhesive tape. In order to reach the desired mechanical rigidity the coils will be winded over a circular metallic strip, with an electrical break, and both (conductor + strip) will be covered by a thick layer of epoxy resin.

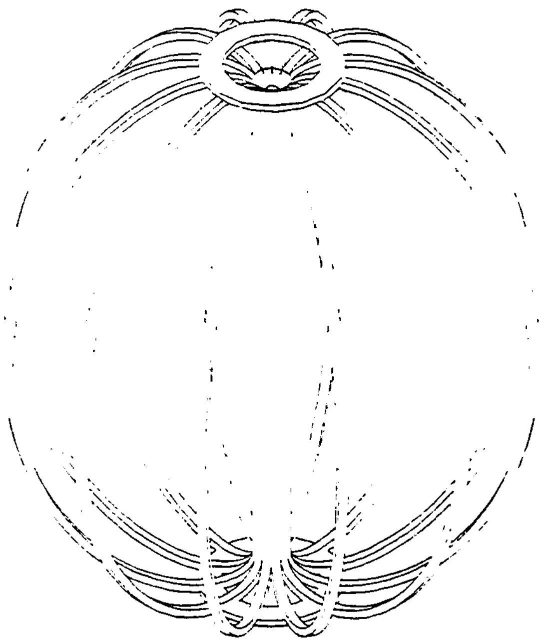

Figure 2. 3D view of the toroidal field coils system for the ETE spherical tokamak

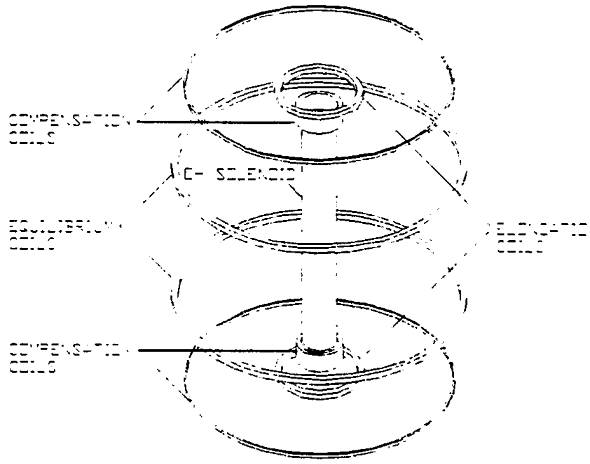

Figure 3. Schematic representation of the poloidal coils system of ETE (magnetizing + equilibrium + elongation)

The magnetizing coils comprises a central solenoid (ohmic heating) connected in series with two pairs of compensation coils (figure 3). The length of the solenoid is 1.3 m and its internal diameter is 0.12 m. The two layers of 130 turns each will be winded over the central column of the toroidal coil. The solenoid can provide a maximum of 0.28 Wb flux variation with double swing operation. A prototype of the solenoid was already made to determine the packing factor and to test the winding machine. The position and number of turns of the two pairs of compensation coils were initially determined by a numerical algorithm which minimize the vacuum error field in the plasma region [6]. The final parameters of the compensation coils are summarized in a paper presented in this conference, which presents a new method (multipole moment expansion for the magnetizing flux) [7].

The other two components of the poloidal field system are the equilibrium and elongation coils (figure 3). These coils are electrically independent and both comprise a pair of coils with 16 turns each. A new method discussed in [7], which employs a direct variational technique and a spectral representation of the flux surfaces plus application of the virtual casing principle was developed in order to calculate the position and currents in the coils. All the materials for the construction of the poloidal coils is already available.

The support structure, shown in figure 4, basically comprises two rings and two crowns of insulating rigid material, 24 stainless steel tubes (diameter of 40 mm) connecting the rings and crowns, and several L-shaped supports for the poloidal field coils and vacuum vessel. The toroidal field coils will be inserted in the grooves localized on the insulating rings. All the material for the structure is already available and the manufacture of the parts was initiated.

A cross section view of the machine is presented in figure 5, showing the vessel, the toroidal field coils, the position of the poloidal field coils and the cross section of the plasma with an elongation of 1.8.

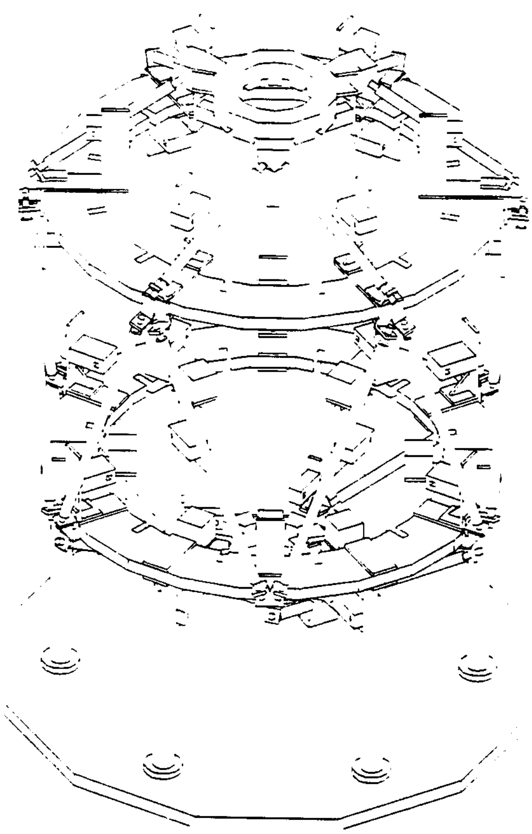

Figure 4. 3D view of the mechanical structure for supporting the coils and the vacuum vessel

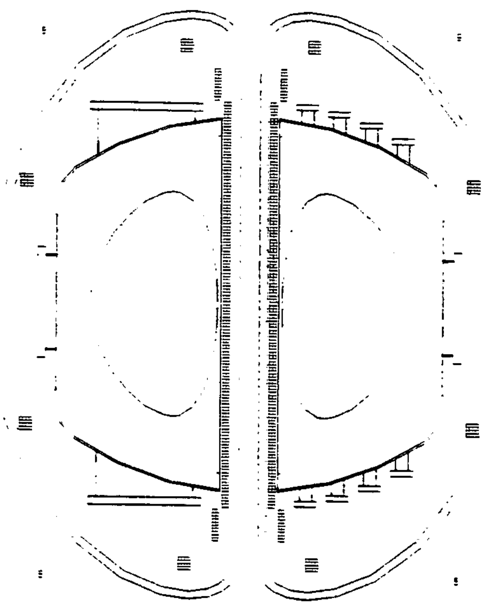

Figure 5. Illustration of a cross section view (poloidal plane) of the ETE tokamak

3. Other components and diagnostics

The power supplies for ETE are based on capacitor banks. As already mentioned, the present number of available capacitors determines the maximum value and duration of the coil currents in the first phase of operation. The toroidal field bank comprises a fast bank (two modules) to ramp up the coil current to 50 kA (0.4 T) and a slow bank (8 modules) sequentially fired to maintain a flattop current for about 100 ms. The total energy of the TF-bank is about 1.2 MJ. The switching is performed by high-power semiconductors. For the second phase of operation it is necessary to increase the number of the modules on both fast and slow banks.

The magnetizing bank is based on double-swing operation and comprises three modules: charging, starting-up and flat-top. This medium voltage bank will be fired by ignitrons. With the available energy (~1MJ) it is expected to attain a plasma current of ~220 kA. With the exception of the power supplies that are being purchased, all the components for the toroidal field and magnetizing banks are already available. Presently, the assembly of these banks is in progress, while the equilibrium and elongation banks are being designed.

The control of the machine (charging of the banks, gas puffing, firing etc.) will be carried out by a personal computer. The system based on CAMAC modules is being developed and incorporates a galvanic insulation between control room and machine area. Data acquisition for ETE will be based on the VME standard. The ADC modules are being purchased from Instituto Técnico Superior of Portugal. An effective personal safety system is being developed for the tokamak operation. The system includes a complete electrical insulation of the machine area from the control room, interlocks, searching scheme, keys, gas detector etc.

Other systems are being developed, i.e., a complete controlled baking system for the vacuum vessel, a glow discharge scheme for wall conditioning, an electron cyclotron resonance pre-ionization apparatus and an adjustable gas puffing unit.

The basic set of diagnostics for the first day plasma comprises a Rogowski coil, magnetic probes, flux coils, diamagnetic probe, Langmuir probes, photomultipliers, soft X-ray camera, hard X-ray detector, visible spectroscopy, mass spectrometer and CCD camera. The diagnostics that will be placed inside the vacuum vessel (Rogowski, magnetic probes and Langmuir probes) have already been specified. The two most important diagnostics for ETE should be Thomson scattering and submillimiter interferometry, which will be specified together with the Plasma Group of Unicamp and the Plasma Group of FEG/Unesp. A beam of lithium ions is presently under development at LAP/INPE to be used for measuring several parameters at the plasma edge.

4. Conclusion

Although the team of the ETE spherical tokamak is fairly small, the main milestones are being reached. It is expected to have the vacuum vessel, the poloidal field coils, the mechanical support structure and the toroidal capacitor bank ready by the end of 96. The first plasma on ETE is planned to be obtained by the end of 97. Thomson scattering and interferometry systems should be ready for operation by the end of 98.

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