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Overview of TJ-II Experiment

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Abstract

The construction and assembly of the flexible Heliac TJ-II located at the Centro de Investigaciones Energéticas MedioAmbientales y Tecnológicas (CIEMAT), Madrid, has recently been finished. The problems encountered during manufacturing this strongly helical machine have been solved satisfactory. Nevertheless the complicated geometry, the low magnetic permeability of all materials and the required narrow tolerances, created real challenges for all the component manufacturers.

First measurements of the magnetic surfaces in the device have been done, using the fluorescent rod technique at electron energies between 100 and 200 eV. A very good agreement has being found between magnetic surface measurements and theoretical predictions. Plasma operation with 1 MW, 53.2 Ghz, ECH system is about to start.

Keywords:

TJ-II, helical axis stellarator, magnetic surface mapping, ECH, NBI

1. Introduction

The flexible Heliac TJ-II is a medium size helical axis stellarator (R = 1.5 m, $<a>$ = 0.2 m, $B(0)$ = 1.0 T) located at the Centro de Investigaciones Energéticas MedioAmbientales y Tecnológicas (CIEMAT), Madrid. TJ-II coil configuration consists of 32 toroidal field coils centered around a toroidal helix of major radius R_0 = 1.5 m, minor radius r_{sw} = 0.28 m, and pitch law $\theta = -4\Phi$, where θ and Φ are the usual poloidal and toroidal angles [1]. Two additional coils, with separately controllable currents, provide its great flexibility ($0.96 \leq \acute{E}_0 \leq 2.5$, $-1\% \leq$mag.well$\leq 6\%$): a circular coil located at the major axis, 1.5 m, and a helical winding wrapped around the circular one, following the same winding law as the toroidal coils. Two vertical field coils complete the coil configuration.

2. TJ-II Construction and Assembly

The budget approval of TJ-II was obtained from EURATOM in 1990, and was followed by a design review phase which was finished towards the middle of 1991. Contract placing and construction followed and the assembly of all stellarator components was finished on October 1996, five years after the first tendering action was started. Magnetic field mapping followed right afterwards. The cost of the experiment is within the estimates done for Euratom phase II application.

All stellarator components of TJ-II were manufactured by the European industry and about 60% was realized by Spanish companies.

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The vacuum vessel has a helical geometry with an average major diameter of three meters and an average minor diameter of 0.8 meters. Its maximum diameter is about five meters. It is made of stainless steel plates of about ten millimeter thickness which have a relative magnetic permeability of below 1.01. The vessel is an all-metal welded design. It consists of 32 sectors which carry a total of 96 ports and 32 rings. These rings connect the sectors ànd provide room for the toroidal field coils. To meet the tolerance requirement which allowed a maximum deviation from the theoretical position of a about one millimeter, a complex manufacturing procedure was developed. This procedure included welding procedures, manifold geometrical checks and thermal heat treatments between the welding operations.

The central conductor of TJ-II is an assembly of one solenoid and two helical coils that spiral around it four times in the poloidal direction during one toroidal passage. The average diameter of the three water-cooled copper coils is three meters. The current densities in the coils are as high as 100 MA/m^2. A stainless steel casing provides the necessary support for the three coils.

The 32 water-cooled toroidal field coils provide a magnetic field of one tesla on the axis of TJ-II when supplied with their nominal current of 32.5 kA. The coils have eight turns each and are made of copper. Four coils have nine turns and are slightly enlarged to provide additional room for the neutral beam injection. The coils are splittable in halves for assembly reasons. The joints of the two halves are the most critical part of the coils.

Four sets of water-cooled poloidal field coils provide the required vertical radial and OH fields. The coils are wound of copper profiles. The support structure which supports vacuum vessel and each coil system independently is made of stainless steel 304 LN and has a total weight of 25 tons.

The vacuum pumping system has four units, each one consisting of a turbopump and a forepump. The

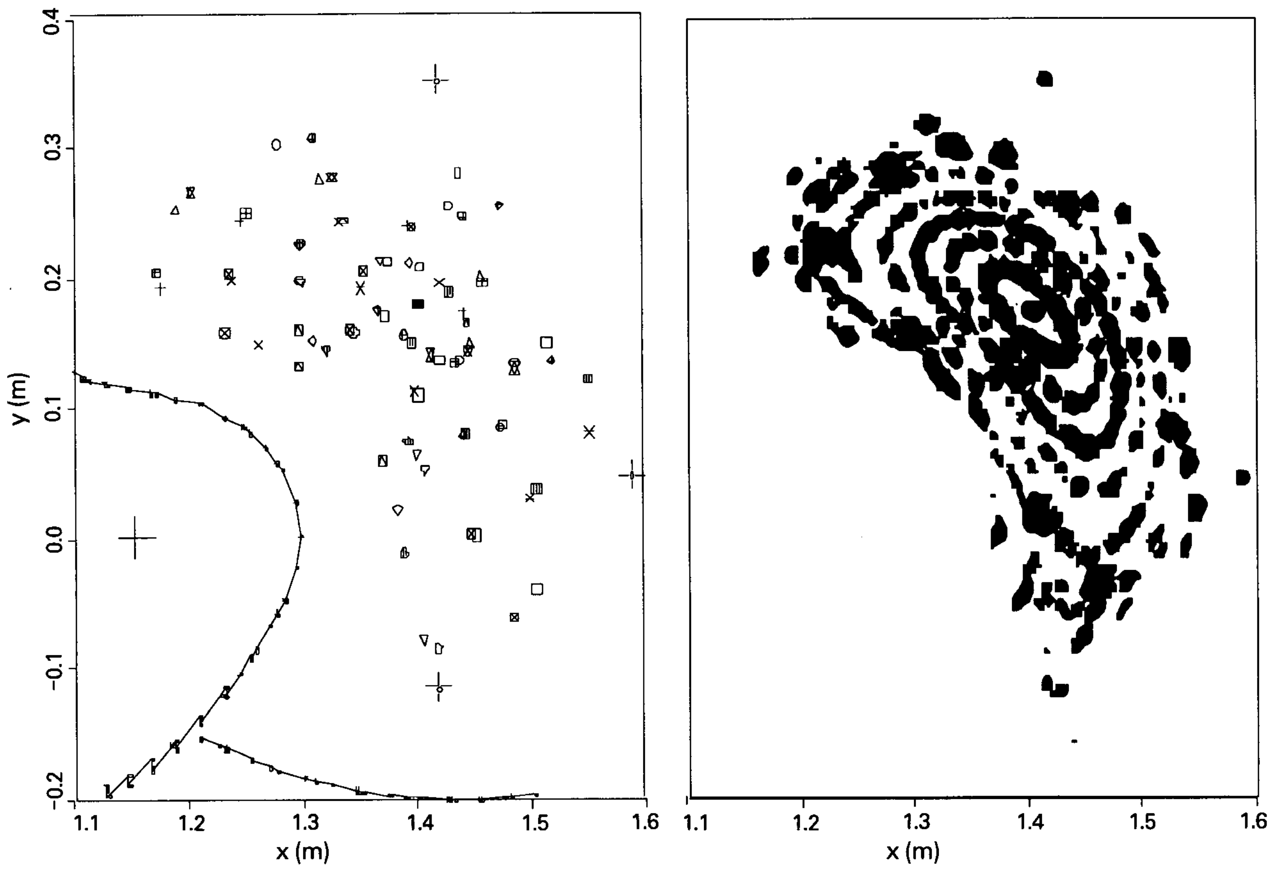

Fig. 1 Left shows the calculated magnetic surfaces using numerical techniques and on the right the measured surfaces for the FAT configuration obtained using a CCD camera showing the excellent agreement between both results.

vacuum tests of the vacuum vessel showed very good vacuum properties and a very low leak rate (a global leak rate as low as 1×10^{-9} mbar·L/s was measured with just one pump).

3. Heating

For TJ-II heating, three phases are foreseen. In the initial phase, we have installed two gyrotrons working at 53.2 GHz, able to deliver between 300–400 kW each into the plasma in the X-mode. A considerable versatility has been introduced into the design of the quasioptical transmission line that will permit to exploit the operational flexibility of the machine. For the second phase, an ORNL loan of two beam lines able to deliver 2 MW of Neutral Beam power is presently being implemented, which will permit to explore the finite beta effects on Heliacs. The third foreseen phase will be completed with two additional MW of power that could come in the form of NBI or ICRH depending on experimental result on TJ-II and other stellarators.

4. Experimental Results

First measurements of the magnetic surfaces in the device have been done using a directed electron beam in combination with a movable fluorescent rod array [2-3]. The magnetic field was steady state, $B_0 \leq 0.05$ T (5% of the nominal field), with 50 s pulse length. The technique used is based on imaging the spots produced by the impact of an electron beam, launched in the vacuum vessel along the magnetic field lines, when intersecting an array of four fluorescent rods (1.5 mm diameter each, coated with P24, ZnO:Zn powder) that sweeps the vessel cross section.

Nine configurations have been measured, covering the iota range $0.96 \leq \iota_0 \leq 1.97$. Figure 1 shows the good agreement between the experimental and calculated magnetic surfaces corresponding to one of the configurations with largest plasma volume, named FAT (0.25 m effective plasma radius; ι ranging between 1.84 and 1.99). In the external part of the theoretical image part of an island corresponding to $\iota = 2$ is clearly visible. It couldn't be resolved in the experiment because it would be partially intersected by the vessel wall, but, probably, this is the reason why the last experimental contour appears to be not clearly closed.

Plasma operation is about to start.

References

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