Topic: FT

Engineering Design Evolution of the JT-60SA Project

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The JT-60SA experiment is one of the three projects to be undertaken in Japan as part of the Broader Approach Agreement, conducted jointly by Europe and Japan, and complementing the construction of ITER in Europe. The mission of JT-60SA is to contribute to the early realization of fusion energy by addressing key physics issues for ITER and DEMO. It is a fully superconducting tokamak capable of confining break-even equivalent deuterium plasmas. It is designed to help ITER optimise the plasma configurations for ITER and DEMO. JT-60SA is hence capable of confining break-even-class deuterium plasmas lasting for about 100 seconds, longer than any timescales characterizing the plasma processes expected in JT-60SA.

Table 1: Typical plasma parameters

Plasma Parameter	High Ip	ITER-shape	High-β_N full-CD
Major Radius R (m)	2.96	2.93	2.97
Minor Radius a (m)	1.18	1.14	1.11
Plasma Current I_p (MA)	5.5	4.6	2.3
Toroidal Field B_o (T)	2.25	2.28	1.71
Plasma Aspect Ratio A	2.5	2.6	2.7
Plasma Elongation κ_x	1.95	1.81	1.92
Plasma Triangularity δ_x	0.53	0.43	0.51
Shape Factor S	6.7	5.7	6.9
Safety Factor q_{95}	3.2	3.2	5.7
Plasma Volume (m^3)	132	122	124
Heating Power (MW)	41	34	37
Assumed HH-factor	1.3	1.1	1.3
Normalized Beta β_N	3.1	2.8	4.3
Thermal τ_E (s)	0.54	0.52	0.26
Electron Density ($10^{20}/m^3$)	0.63	0.91	0.50
Normalized Density n_e/n_{GW}	0.5	0.8	0.86
Bootstrap current fraction	0.29	0.30	0.66
Flattop duration (s)	100	100	100

The Tokamak has been designed to pursue full non-inductive steady-state operations at high values of the plasma pressure exceeding the no-wall ideal MHD stability limits. For this purpose, JT-60SA has been designed to realize plasma equilibrium covering relatively high plasma shaping with a low aspect ratio A~2.5 at a maximum plasma current of I_p=5.5 MA.

In late 2007 the BA Parties, prompted by cost concerns, asked the JT-60SA Team to carry out a re-baselining effort with the purpose to fit in the original budget while aiming to retain the machine mission, performance, and experimental flexibility. Subsequently, along 2008, the Integrated Project Team has undertaken a machine re-optimisation followed by engineering design activities aimed to reduce costs while maintaining the machine radius and plasma current. This effort led the Parties to the approval of the new design in late 2008 and hence procurement activities have commenced.

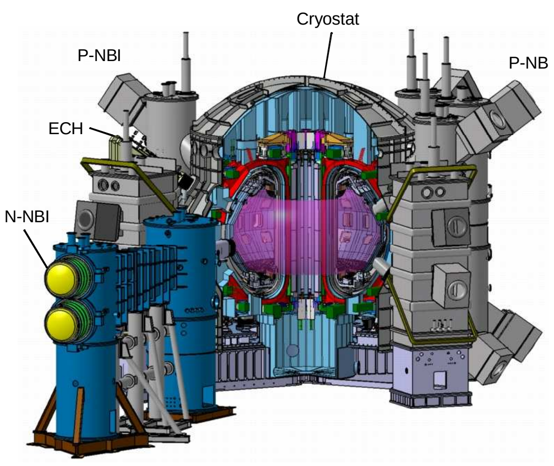

Fig.1 Bird's eye view of JT-60SA

Due to the close linkage of all system parameters in a Tokamak, design changes have resulted in the TF magnet, plasma, vessel and in-vessel components, thermal shield, and cryoplant, allowing an improvement in the design of these components as well as increased confidence regarding their cost. The main driver of the cost reduction has been the reduction of the plasma aspect ratio which resulted from system level analyses. Such reduction of R/a basically meant the shift of space previously allocated to the magnet to the plasma. The increase of the plasma minor radius made possible a reduction of the peak magnetic field of the magnet. This in turn led to important cost reduction drivers, mainly a reduction of the number of turns, the size of the conductor, and hence the total amount of superconducting NbTI strand (from ~90 tons to about 35 tons). Such reduction was largely made possible by the fact that the previous system design required the NbTi strand to operate at a field of about 6.5 T where the value of Jc is rather low at 4.5K and assuming a suitable temperature margin.

In parallel to the system level re-optimisation driven towards the lowering of the aspect ratio, a significant effort was carried out to redesign and re-optimise individual components and systems. As an example, the TF magnet structural concept was modified finally resulting to a reduction of the weights of the casings and intercoil structures, from about 750 tons to about 300 tons. At the same time the PF system was redesigned as well resulting in an enhancement of the plasma shape control together with a reduction of the number of PF coils from 7 to 6 and a reduction of the total conductor length of about 30%.

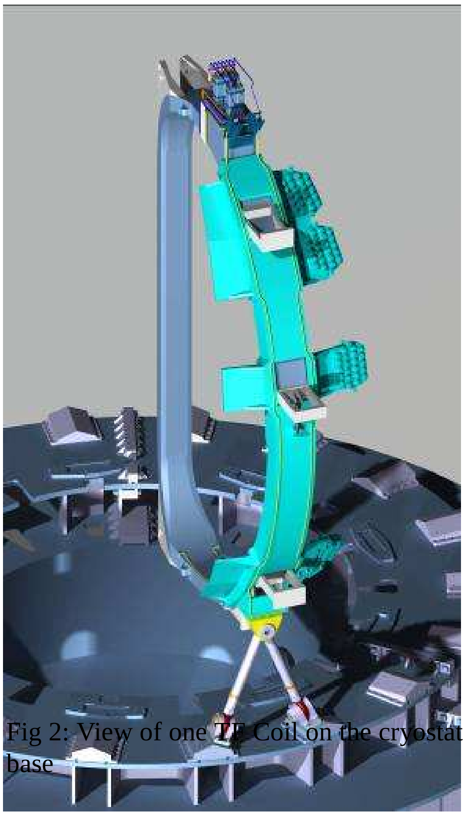

Fig 2: View of one TF Coil on the cryostat base

The superconducting magnet system of JT-60SA consists of 18 Toroidal Field (TF) coils, a Central Solenoid (CS) with four modules, six Equilibrium Field (EF) coils. For all superconducting magnets, high temperature superconductor current leads are used to reduce cryogenic load. Each TF coil has a D-shaped form and is wound from a rectangular steel-jacketed N_bT_i cable-in conduit conductor wound in 12 pancakes each with 6 turns. The PF magnet is composed of the CS and EF coils using $N_{b3}S_n$ and N_bT_i cable-in conduit conductors, respectively. The Superconducting magnet, together with its thermal shields and current leads, are cooled by means of a cryogenic system whose design was carefully optimised, in large part due to the pulsed nature of the Tokamak, in order to reduce costs. The vacuum vessel (VV) is composed of 18 toroidal sectors constructed with low cobalt SS to reduce activation levels. A flow of boric acid water between inner and outer shells is employed to enhance neutron shielding. The divertor consists of inner and outer vertical targets with a V-shaped corner for the outer one to enhance particle recycling and reduce target heat flux, a private flux region dome, inner and outer baffles capable of withstanding a medium heat flux, and a divertor cassette body. Cryopanels will be installed below the divertor cassette for particle control. Three sets of copper coils consisting of a pair of fast plasma position control coils, 18 error field correction coils and 18 RWM control coils will be installed inside the VV. Fast plasma position control coils are situated between the VV and the stabilizing plate for holding horizontal plasma position and suppressing vertical instability. The cryostat consists of a vessel body and a base used for the gravity and seismic support of the machine. The vessel body is formed by cylindrical sections connected by truncated-conical elements in the inclined port sections. Other components such as thermal shield, power supplies, cryogenic system, water cooling system, N-NBI/Positive ion NBI (P-NBI)/ECH systems have also been consistently designed.

The rebaselining of JT-60SA carried out in 2008 and the ensuing detailed design in 2009 were carried out in order to reduce the expected costs as well as in order to finalise technical specifications of the key components. Following this the procurement implementation of the components has been initiated in both Japan and EU.