Recent Progress of JT-60SA Project

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JT-60SA Project is implemented under the Broader Approach (BA) Agreement between EU and Japan as well as the Japanese national fusion programme.

Mission:
Contribute to the early realization of fusion energy by addressing key physics and engineering issues for ITER and DEMO.

Major Objectives:
(1) Supportive Researches for ITER
   JT-60SA starts operation in 2019
   → address ITER related issues in advance
       and optimize its operation scenarios
       under the break-even condition
(2) Complementary Researches for DEMO
   study long sustainment of high integrated
   performance plasmas with high $\beta_N$ value
(3) Foster Next Generation
   build up experience of young scientists and
   technicians who will play leading roles in
   ITER and DEMO.

Plasma Current: 5.5 MA
Toroidal Field: 2.25 T
Major Radius: 2.96 m
Minor Radius: 1.18 m
Elongation, $\kappa_X$: 1.87
Triangularity, $\delta_X$: 0.50
Safety factor, $q_{95}$: 3.0
Plasma Volume: 131 m$^3$
Heating Power: 41 MW
Normalized beta, $\beta_N$: 3.1
Long sustainment of high integrated performance plasmas with high $\beta_N$ value for DEMO will be investigated by making the best use of (1) powerful and versatile NBI&ECRF system, (2) flexible plasma shaping, (3) various kinds of in-vessel coils, and so forth.
Share of JT-60SA Components and Systems (remarkable progress since the last IAEA FEC)

Existing JT-60 facilities (e.g. transformer substation, motor generators, etc.) are also reused as much as possible to reduce overall project cost.
(1) winding pack (WP) fabrication

(2) impregnation of WP

(3) WP enclosed in coil casing

(4) final machining

(5) completed TF coil

18 TF coils plus 2 spare TF coils are being fabricated in France and Italy.

TF coil cross section

NbTi conductor (26mmx22mm)
Two TF coils now in Naka Site

(6) performance tests at cryogenic temperature @CEA Saclay

(7) OIS preassembly

(full current test, quench test, etc.)

(8) delivery to Naka Site

1st coil “Annie”

2nd coil “Brigitte”

3rd coil “Roberta”

coming on the Pacific Ocean

TF coil assembly around the vacuum vessel will start in December 2016.
All EF coils were manufactured with excellent accuracy in the circularity for minimizing error field.

<table>
<thead>
<tr>
<th></th>
<th>Diameter</th>
<th>Circularity</th>
<th>Requirement</th>
<th>fabrication</th>
</tr>
</thead>
<tbody>
<tr>
<td>EF1</td>
<td>12.0 m</td>
<td>0.3 mm</td>
<td>≤8 mm</td>
<td>Aug. 2016</td>
</tr>
<tr>
<td>EF2</td>
<td>9.6 m</td>
<td>0.4 mm</td>
<td>≤7 mm</td>
<td></td>
</tr>
<tr>
<td>EF3</td>
<td>4.4 m</td>
<td>0.2 mm</td>
<td>≤6 mm</td>
<td>Feb. 2013</td>
</tr>
<tr>
<td>EF4</td>
<td>4.4 m</td>
<td>0.6 mm</td>
<td>≤6 mm</td>
<td></td>
</tr>
<tr>
<td>EF5</td>
<td>8.1 m</td>
<td>0.6 mm</td>
<td>≤7 mm</td>
<td>Jan. 2014</td>
</tr>
<tr>
<td>EF6</td>
<td>10.5 m</td>
<td>1.3 mm</td>
<td>≤8 mm</td>
<td></td>
</tr>
</tbody>
</table>

EF4, EF5 and EF6 are temporally placed on the Cryostat Base.
JT-60SA has 4 identical Central Solenoids (CS)

(1) winding of conductor

One CS module is composed of 7 pancakes (6 OP and 1 QP).

(2) insulation and stacking

(3) impregnation

(4) 1st CS module is now in NIFS waiting for cold test.
High Temperature Superconductor Current Leads (HTS-CLs) using bismuth alloy (Bi-2223/AgAu) saves cooling power of the cryogenic system. (6 HTS-CLs (25.7kA) for TF coils, 20 HTS-CLs (20kA) for EF coils and CS)

- External current feeder (60 K)
- Superconducting feeder (4.4 K)

Coil Terminal Box (CTB) (for current feeding)

Valve box (VB) (for cold helium feeding)

Cryogenic transfer line

HTS-CLs for TFC (test facility CuLTKa in KIT)
Cryogenic Plant has been newly constructed in the Naka Site.

Refrigerator Cold Box & Auxiliary Cold Box

Helium Storage vessels

Warm Compressors

Construction Work in Naka Site

Naka Site on 7 April 2015

Naka Site on 27 May 2015
Commissioning of the Cryogenic System was successfully completed.

- The total power equivalent at 4.5K is about 9kW. (world largest class refrigerator for a fusion plant before ITER)
- Adoption of Auxiliary Cold Box facilitates heat load smoothing.
- Actual operational condition were tested and validated by the commissioning in Sep. 2016.

![Heat pulse through TFC and PFC](image1.png)

**Graph:**
- Heat pulse through TFC and PFC
- Average load for cryogenic system

![Cryogenic Hall](image2.png)

![Compressor Building](image3.png)

Auxiliary Cold Box (ACB)          Refrigerator Cold Box (RCB)

- six He gas storage vessels
- LN$_2$ tank
- 8 warm compressors
Fabrication of three cryostat parts

- Cryostat Top Lid
- Cryostat Vessel Body Cylindrical Section
- Cryostat Base

260 ton, 12 m\(\phi\)
175 ton, 13.5 m\(\phi\)
45 ton, 11.6 m\(\phi\)

(discussion analysis) max. 1.6mm

detailed design completed

assembled in March 2013
under fabrication
340° Vacuum Vessel was completed

- Completed in Aug. 2015
- Fabricated at factory
- Jointed at Naka-site

First delivery of 40° inboard sector in Apr. 2011
Thermal Shields are being installed.

(inside the vacuum vessel)

6.3 m (inside dimension)

40° VVTS

in the VVTS manufacturer

High dimensional accuracy was achieved by careful welding work.

<table>
<thead>
<tr>
<th></th>
<th>actual</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>horizontal</td>
<td>±5 mm</td>
<td>±30 mm</td>
</tr>
<tr>
<td>vertical</td>
<td>-4 mm</td>
<td>+6/-4 mm</td>
</tr>
</tbody>
</table>

(Welding shrinkage in the torus direction was adjusted by welding with splice plates.)

VVTS assembly will be completed in Nov. 2016.
Power Supply System

SCMPS (Superconducting Magnet PS)
Base PS to provide DC current to the SC coils
PS for EF2~EF5 and TF coils
delivered to Naka in June 2016
PS for CS1-4 modules, EF1,EF6 coils
to be delivered in 2017

QPC (Quench Protection Circuit)
Protection of SC coils when quench or PS failure occur
10 units for EF coils and CS modules
3 units for TF coils,
Commissioning in June 2015

Motor Generator (reused facility)
Provide power for P-NBI, N-NBI, EF&CS PS
H-MG: 18kV/400MVA, 2.6GJ
T-MG: 18kV/215MVA, 4.0GJ
Overhaul of H-MG was carried out in 2015

delivered to Naka in Oct 2016

SNU (Switching Network Unit)
Booster PS to provide high voltage for plasma breakdown and current ramp-up
delivered to Naka in Oct 2016
Powerful and versatile heating/CD by NBI and ECRF (41MW in total)

**NBI system**
- P-NBI, 85keV, 12 units × 2MW = 24MW, 100s tangential 4u (CO:2u, CTR:2u), Perpendicular: 8u
- N-NBI, 500keV, 2 units × 5MW = 10MW, 100s tangential, off-axis

**ECRF system**
- 9 Gyrotrons, 4 Launchers 7MW in total
  - <5kHz power modulation
- movable mirror at launcher
- multi-frequency gyrotron
  - 110GHz(2nd) (1MW, 100s) +
  - 138GHz(2nd) (1MW, 100s) +
  - 82GHz(fund.) (1MW, 1s)
    (start-up assist, wall cleaning)

Beam acceleration of 85 keV was successfully demonstrated for 100s (P-NBI).

Heating, current-drive and momentum-input profiles can be flexibly controlled.
Overall Progress of JT-60SA Project

JT-60SA assembly (Cryostat Base)

- Mar. 2013

- Operation starts in 2019

EF coils

- We are here!

Vacuum Vessel

- Mar. 2013

- Jan. 2014

- Sep. 2015

TF coils

we are here!

- VV Thermal Shield (340 deg.)

- Magnet interface (HTS-CL)

lower EF coils

- Vacuum Vessel (340 deg.)

- power supplies

- SNU

- QPC

- SCMP

- NBI

- ECRF

- diagnostics

- MG-set
Research Phases of JT-60SA

- JT-60SA research phase starts with Hydrogen operation to conduct full commissioning.
- JT-60SA is upgraded step by step.
  (power/duration of P-NBI&ECRF, divertor target material, remote handling availability)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Expected Duration</th>
<th>Annual Neutron Limit</th>
<th>Remote Handling</th>
<th>Divertor</th>
<th>P-NB 85keV</th>
<th>N-NB 500keV</th>
<th>ECRF 110 GHz &amp; 138GHz</th>
<th>Max Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Research Phase</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>phase I</td>
<td>1–2 y</td>
<td>H</td>
<td>–</td>
<td>LSN partial-monoblock Carbon Div. Pumping</td>
<td>10MW</td>
<td></td>
<td></td>
<td>23MW</td>
</tr>
<tr>
<td>phase II</td>
<td>2–3 y</td>
<td>D</td>
<td>4E19</td>
<td>Perp.</td>
<td></td>
<td>1.5MW x100s + 1.5MW x5s</td>
<td>33MW</td>
<td></td>
</tr>
<tr>
<td>Integrated Research Phase</td>
<td>2–3 y</td>
<td>D</td>
<td>4E20</td>
<td>LSN full-monoblock Carbon Div. Pumping</td>
<td>13MW</td>
<td>10MW</td>
<td></td>
<td>37MW</td>
</tr>
<tr>
<td>phase I</td>
<td>&gt;2 y</td>
<td>D</td>
<td>1E21</td>
<td>DN/SN full-monoblock Metal or Carbon Advanced Structure</td>
<td></td>
<td>7MW</td>
<td></td>
<td>41MW</td>
</tr>
<tr>
<td>phase II</td>
<td>&gt;5 y</td>
<td>D</td>
<td>1.5E21</td>
<td>Use</td>
<td>24MW</td>
<td></td>
<td></td>
<td>41MW x 100s</td>
</tr>
</tbody>
</table>
Research collaboration on JT-60SA Project is strongly promoted.

EU and JA fusion community members join “JT-60SA Research Unit” to study key physics and engineering issues of ITER and DEMO.

JT-60SA Research Plan (ver. 3.3) written by 378 authors from EU/JA was open to public in March 2016. http://www.jt60sa.org/pdfs/JT-60SA_Res_Plan.pdf

JT-60SA target region covers ITER target and DEMO target. Thus their acceptable parameters will be investigated by JT-60SA operation.
JT-60SA as a flexible ‘Test Stand’ for ITER

- ITER like operation environment
  - ITER like non-dimensional parameters, small-torque input
  - Electron heating dominant plasma (by N-NBI, ECRF)
  - Large fraction of energetic particle (500 keV N-NB)
  - Operation scenario optimization with superconducting coils.

- High Plasma Performance
  - H-mode operation (H, He, D) study ($I_p \sim 5.5$ MA) towards $Q=10$
    - L-H transition, Pedestal Structure, Confinement Improvement
    - H-mode compatibility with radiative divertor, RMP, etc.
    - Confinement in high $n_{GW}$ regime
    - Effect of Local Ripple, Error Field / noise on confinement
  - Improved H-mode (Hybrid) operation with ITER-like shape ($I_p \sim 4.6$ MA)

- Divertor Integrity
  - ELM mitigation (RMP, pellet pacing, etc.) & small / no ELM regime at low $\nu^*$
  - Divertor Heat Load reduction (radiative divertor, ITER-like divertor config.)
  - Disruption avoidance & mitigation at high $I_p$ (MGI, etc.)

- High $\beta_N$ plasma
  - MHD instability suppression at small~zero rotation condition
Core-edge coupled predictive modeling of JT-60SA high-beta steady-state plasma with impurity accumulation has been studied.

Ar seeding is effective for reduction of divertor heat load below 10 MW/m². Ar^{16-18+} accumulation in core causes slight decrease of temperature, which is fully recoverable by additional core heating.

Optimized combination of \( B_H \) and \( B_V \) are required for effective wall conditioning.

EC Wall Conditioning (ECWC) experiments to support JT-60SA operation have been performed by TCV.

ECWC efficiency assessed from amount of released \( D_2 \) fuel →

Ion saturation current profile changes with \( B_H \) and \( B_V \). ↓

1.5D core transport solver (TOPICS) + IMPACT using SONIC Ar edge densities →

Ar density profile calculated by SONIC

Ar edge densities →
1. Fabrication, installation and commissioning of JT-60SA components and systems procured by EU and Japan are steadily progressing. TF coil assembly around the vacuum vessel will start soon. JT-60SA starts operation in 2019.

2. Powerful and versatile NBI/ECRF system, flexible plasma shaping, various kinds of in-vessel coils are advantage of JT-60SA for plasma control.

3. JT-60SA will explore ITER and DEMO relevant parameter region in advance for the purpose of optimization of their operational scenarios, especially in high $\beta_N$ (≈5) region.

4. Close research collaboration between EU and Japan has been promoted. JT-60SA Research Plan v.3.3 by 378 researchers from EU and Japan released in March 2016 elaborates on key physics and engineering issues to be addressed for ITER and DEMO.
## JT-60SA related presentations in this conference

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<thead>
<tr>
<th>Date</th>
<th>Presentation</th>
<th>Title</th>
</tr>
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<tbody>
<tr>
<td>18 Oct (Tue)</td>
<td>FIP/1-3Ra (J. Hiratsuka)</td>
<td>Long-pulse acceleration of 1MeV negative ion beams toward ITER and JT-60SA neutral beam injectors &amp; towards powerful negative ion beams at the test facility ELISE for the ITER and DEMO NBI system</td>
</tr>
<tr>
<td></td>
<td>TH/P1-18 (T. Bolzonella)</td>
<td>Securing high $\beta_N$ JT-60SA operational space by MHD stability and active control modelling</td>
</tr>
<tr>
<td></td>
<td>TH/P2-19 (N. Hayashi)</td>
<td>Core-edge coupled predictive modeling of JT-60SA high-beta steady-state plasma with impurity accumulation</td>
</tr>
<tr>
<td></td>
<td>TH/P2-20 (M. Romanelli)</td>
<td>Investigation of Sustainable Reduced-Power non-inductive Scenarios on JT-60SA</td>
</tr>
<tr>
<td>19 Oct (Wed)</td>
<td>FIP/P4-42 (C. Day)</td>
<td>Assessment of the operational window for JT-60SA divertor pumping under consideration of the effects from neutral-neutral collisions</td>
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<tr>
<td>20 Oct (Thu)</td>
<td>TH/P6-24 (R. Zagorski)</td>
<td>Numerical analyses of baseline JT-60SA design concepts with the COREDIV code</td>
</tr>
<tr>
<td>21 Oct (Fri)</td>
<td>FIP/P7-37 (J.-C. Vallet)</td>
<td>Towards the completion of the CEA Contributions to the Broader Approach Projects</td>
</tr>
<tr>
<td></td>
<td>EX/P8-31 (D. Douai)</td>
<td>Development of Helium Electron Cyclotron Wall Conditioning on TCV for the operation of JT-60SA</td>
</tr>
<tr>
<td></td>
<td>EX/P8-40 (G. Giruzzi)</td>
<td>Physics and operation oriented activities in preparation of the JT-60SA tokamak exploitation</td>
</tr>
<tr>
<td></td>
<td>FIP/4-1Ra (Y. Shibama)</td>
<td>Assembly Technologies of the Superconducting Tokamak on JT-60SA</td>
</tr>
<tr>
<td></td>
<td>FIP/4-1Rb (P. Decool)</td>
<td>JT-60SA TF Coil Manufacture, Test and Preassembly by CEA</td>
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</tbody>
</table>