GYROTRON SOURCE SYSTEM
FOR ITER PLASMA START-UP

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Presented by : S.L. Rao
Plan of the presentation

- Introduction
- Start-up source requirements
- Start-up source package
- Source system description
- Test setup
- Project execution plan
- Schedules
- Summary
ITER has limited ohmic electric field for the plasma start-up
- ~0.3 V/m

Limited electric field may only support a narrow operating parameters
- Fill Pressure
- Error field
- Impurity

EC assist has been proven to produce reliable breakdown even with limited loop voltage
- Experiments on DIII-D, JT-60U etc

ITER ECH system includes
- ECH start-up sources

Start-up source requirements

- **Power & Pulse length**
  - Impurity Burn through requirements
    - 3 MW (Installed power)
    - 10 s (Max)

- **Frequency**
  - Resonance layer should lie within error magnetic field null zone
    - Outboard side null zone (R=7.48 m ± 0.8 m)
  - Torus window compatibility
    - ~ 127 GHz (R~7.2 m)

- **Modulation & Duty factor**
  - No specific requirements

ITER, Project Integration Document (PID), Release 3.0, Jan 07
Startup source-Package

Electron Cyclotron Heating & Current Drive (EC H&CD) system in ITER is used for:

- Plasma Start-Up
- Plasma heating
- On axis and off-axis current drive.
- Discharge cleaning?

EC H&CD SYSTEM

Heating & Current Drive
24 MW at 170 GHz

Plasma Start-Up
3 MW at ~127 GHz

5.2.G ECH Start Up Package
START UP SOURCE PACKAGE

- High power Gyrotron tubes: 3 Sets
- Auxiliary Power Supplies for the gyrotron tubes: 3 Sets
- Gyrotron Oil Tank with HV circuitry: 3 Sets
- Data acquisition, Protection & Controls: 1 Set
- Cooling connections & Instrumentation: 3 Sets
- Main High Voltage Power Supply: 1 Set
- Anode High Voltage Power Supply: 3 Sets
- Testing and commissioning at ITER site
GYROTRON SYSTEM DESCRIPTION

Acquistion & Controls

Tubes

HVPS

AUXPS

Cooling
GYROTRON TUBES

Main Specs

- Frequency: ~127 GHz
- Power: 1 MW
- Pulse: 10 s (Max)
- Efficiency: ~50%
- Type: Depressed Collector
- Output mode: Gaussian TEM$_{00}$

Realization

- Short Pulse tubes
- Expected to be commercially available
- Market survey has been carried out
  - Responses are positive
- Procurement against FS / Other options

Tube Configuration

Diode type configuration would be adopted
This would lead to simpler PS configuration
Auxiliary Power Supplies

- **FPS : Filament Power Supply**
  - AC / 25 V / 40 A / 1% V-stability

- **CRMPS: Cryo Magnet PS**
  - DC/50-100 A
  - Current-stability 0.05%
  - Typical Load Inductance : ~ 10 H

- **VIPS: Vacuum Ion pump PS**
  - Voltage (DC): 3-4 KV; Current : ~ 1mA

- **CCPS: Collector Coil PS**
  - Current : ~ 60 A; Pulse shape : triangular
  - Pulse duration : 100 ms ;Coil -L : ~ 0.2 H
High Voltage PS

- Two High Voltage PS
  - MHVPS
  - AHVPS
- PSM type HVPS
  - Fast turn off < 10 µs
- All the three tubes are fed from a single MHVPS
- Individual AHVPS
- Each gyrotron circuit would have
  - Fast over current switch
  - Isolation & Ground switch for safety

Main High Voltage PS
- Voltage ~ 65 kV
- Current ~ 140 A
- Type PSM type
- Maximum fault energy dump < 10
- Fault turn off ≤ 10 µs
- Ripple ~ 1.0 %
- Duty ~ 5 %
- No of units 1 unit

Anode High Voltage PS
- Voltage ~ 30 kV
- Current ~ 200 mA
- No of units 3 units
The gyrotron operation would require a control, protection & monitoring sys.

ITER envisages a three tier hierarchical system
- CODAC-EPMC -LC

For the three start-up gyrotrons there would be a Local controller (LC)
- stand-alone mode on dummy loads
- Under the supervisory role of the ECMC/CODAC.

Requirements for the DAC system
- Control signals
- Sequential start-up & shutdown
- Monitoring
- Protections & Safety Interlocks
- Fast (<10µs) – Hardwired
  - Arcing, Rate of rise beam current, Vacuum etc
- Slow (~100 ms)
  - Cooling etc

Data acquisition for post processing
- Data archival & visualization.
DATA ACQUISITION AND CONTROL SYSTEM

MICROWAVE SIGNALS

PROTECTION SIGNALS
Internal/External Arcs, Vacuum errors etc

DAC CONDITIONING RACS

FAST INTERLOCKS

SLOW INTERLOCKS

COOLING
AUX -PS
HVPS

Local controller

Data Logger

Slow Interlocks
The gyrotron tubes would require considerable rates of cooling.

The most crucial are the collector on to which the entire spent beam power would be dissipated. At 45% efficiency this would be about 1.2 MW.

Another crucial element is the cavity where the heat-flux dissipation would be typically of the order of 2 kW/cm².

The gyrotron tubes typically would have 4-5 cooling circuits with different ratings.

Some of the gyrotron manufacturers would recommend having a separate window circuit with anti-corrosion agents like CC-15.

Each gyrotron typically would require about 1000-1500 lpm of total flow (manufacturer specific).
TYPICAL GYROTRON COOLING SPECIFICATIONS

120GHz/1MW

Collector

MOU

Body/Lower body

Dummy water load

Window

Oil tank

Anode-Cavity/Upper body

Collector

GYROTRON

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Testing

- **Gyrotron tubes tests**
  - Factory acceptance tests

- **Integrated system tests**
  - A test facility is planned at IN-PT
  - Integrated tests would be performed
  - At least one set of calorimetric dummy load and other waveguide components would be procured

- **Power**
  - Calorimetric water load
  - Directional coupler signal

- **Frequency**
  - Frequency counter
  - Mixer down converter + Spectrum Analyzer

- **Mode Purity (at factory)**
  - IR Image analysis
  - Burn patterns
TYPICAL GYROTRON TEST SET UP

120GHz/1MW

Matching Optic Unit

Dual Directional Coupler

Frequency Monitoring Power Monitoring

Dummy water load

Corrugated Waveguide 63.5 mm (Al)

TMP Vacuum Pumping sys.

Calorimetric Power Meas.
Project Execution

- Basic System Design
- Procurement
- Manufacturing
  - Design
  - Manufacturing
  - Testing at the factory
- Shipping to IN-PT site
- Assembly & Integration at IN-PT site
- Integrated tests at IN-PT site
- Dis-assembly & Packing
- Delivery to ITER site
- Installation at ITER site
- Commissioning at ITER site
Project Schedules
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- **Required first delivery at ITER site**: Dec-2013
- **RF building ready for installation**: JUNE,2014
Summary

- Because of the limited available loop voltage, ECH assisted plasma start up is planned on ITER.
- The required source specifications have been mainly defined from the burn through requirements & error field null zone. Start up source procurement package mainly consists of delivery of three, 1MW short pulse gyrotrons along with other auxiliary sub systems.
- The Indian Participating team holds the responsibility of delivering the package along with the required high voltage power supplies for start up.
- The source system with its major sub systems have been briefly defined along with the major specifications.
- Test plans have been outlined.
- Finally the project execution plan has been presented.
THANK YOU