The ICRH System for the Ignitor Experiments

Ignitor Project

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Abstract

The ICRH system is an integral part of the Ignitor experiment as it provides the flexibility to reach ignition regimes following different paths in parameter space and, in particular, by shortening the time needed for this. Another important use of the ICRH is to maintain the plasma in a slightly sub-ignited state, avoiding the excitation of the thermonuclear instability, under quasi-stationary conditions, for the entire duration of the plasma current flat-top. The ICRH system is structured with a modular configuration and launches the power into the plasma through RF strap-antennas based on 4 straps, grouped in two poloidal pairs, per port. The system is designed to operate in the frequency band 80-120 MHz generating a total power up to 12 MW at the lower frequencies. Each module consists of 4 high power generators whose power is split over two ports (8 straps) in order to keep the maximum electric field (especially in the vacuum region of the straps and transmission line) below 5kV/cm. A 30 vacuum transmission line, including the feedthrough, transfers the power of 0.4 MW to each strap with a total power of 1.6 MW per port. The RF configuration of the modules allows a full phase controls (toroidal and poloidal) of the straps though a PLL phase control. Two modules, distributed over 4 ports, can produce about 6 MW at 120 MHz in order to attain ignition with a limited RF pulse during the plasma heating phase.

Evaluation of RF performance of plasma-facing components

Critical task for design: need dependable analysis tool

RF design based on performance evaluation obtained with the TOPICA© simulation suite (TOrino Polytechnic Ion Cyclotron Antenna code)

Extensively tested: validated against commercial codes (in vacuo), ICANT and RANT3D (where applicable), against measurements of in-house and CEA mockups, against data in literature

TOPICA© simulation suite

- 3D antenna structure model (including FS, box)
- 1D plasma, non-homogeneous, FLR, absorption (FELICE code)
- Structure geometry drawn in CAD (e.g. Autocad®) and imported into TOPICA core
- Multi-port (typ.: 4 ports) circuit parameters (Z, Y, S matrices) calculation
- Coax, Voltage and current excitation of strap ports
- Accurate model of coaxial-to-strap feed
- Computes current, fields, and voltage everywhere around antenna and housing
- Boundary-element method, high efficiency, controllable convergence, affordable (yet important) CPU times (fastest guy in town…)

See Also Poster NP1.00016 :
“The IGNITOR ICRF system”
Volodymyr Kyrytsya, Riccardo Maggiora, Vito Lancellotti, Daniele Milanesio, Giuseppe Vecchi

System specifications, constraints and input conditions

Main design requirements:

1. 3 to 12 MW generated
2. 4 to 6 ports allocated
3. 1-4 s RF pulse length
4. 16 x 80 cm access port dimensions
5. Withstanding of :
   - Specified thermal loads
   - Vertical Displacement Event (VDE) stresses
   - Specified neutron flux
6. Compliance with Remote Handling for assembly and maintenance
7. Variable frequency and multiple heating scenarios

Optimal Heating Schemes for Ignition

- The RF system needs to operate on plasmas of different composition (D-T), with ramping magnetic fields (9 to 13 T) and plasma currents (6 to 11 MA). Flexibility is also required for other operational scenarios.
- The system can access a frequency range 70 <*f*< 120 MHz. The optimal results are obtained around 115 MHz ($2\Omega_{cT}$) and at power levels of 3 to 6 MW, coupled to the plasma by means of 2+2 strap antennas on 4(+2) ports of the machine.
- Different heating scenarios can be used during the magnetic field ramp:

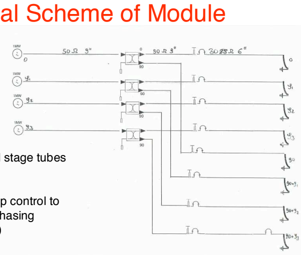
1) at B= 9 -10T the 2nd harmonic of D (the role of the 1st harmonic H impurity need to be established);
2) at B>10T the 2nd harmonic of T (in this case the 2nd D harmonic is out of the plasma column while the 1st is on the high field side of the plasma column.

System Architecture

The ICRH system has a modular configuration with the following performances per module:

Operating Frequency Range	80 – 120 MHz
Max RF Power @ 115 MHz	3.6 MW (generator)
Max RF Power @ 80 MHz	8 MW
Pulse Duration	4 s
Generator Type:	Cavity Coupled RF Tetrode
Antenna Type	Four Strap
Generators per Module (Strap)	4
Antennas per Module	2

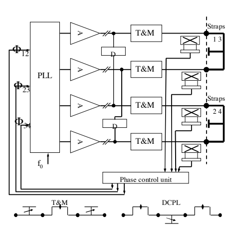
Main Electrical Scheme of Module



Generators

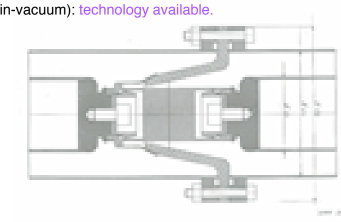
- 4 systems with Diacrode® final stage tubes
- Pmax = 1 MW at 80 MHz
- Phase-locking (PLL)
- Phase controlled by closed-loop control to enforce desired strap current phasing (overcome inter-strap coupling)

Out-of-vessel feeding system

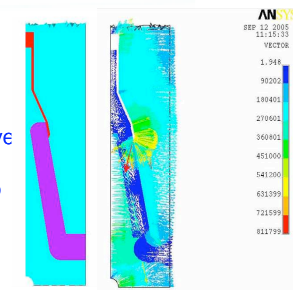


In-vessel feeding system

Feed-through (ceramic window between pressurized and in-vacuum): technology available.



Details of construction for the coaxial feedthrough have been defined using ANSYS to meet the requirement of E < 5 kV/cm



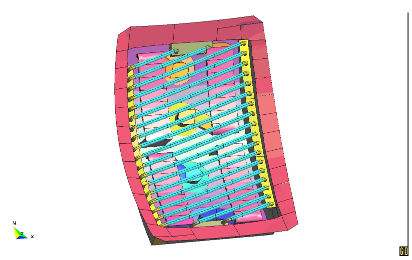
Vacuum Transmission Lines

- 50 Ohm
- External diameter: 155 mm
- inner conductor supports: ceramic disks
- with holes for vacuum pumping (“all-metal support” not feasible because of space constraints)

Coax (pressurized, 42psig) 50-Ohm lines

- Spinner 150-345
  Vmax > 100 kV
  Ø 355 mm
- Spinner 6 1/8”
  Vmax = 50 kV
  Ø 155 mm

Antenna



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