The Status and Design Challenges of the Heating and Current Drive Systems for DTT

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Introduction

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Divertor Tokamak Test facility aims

- Power exhaust studies in reactor relevant conditions (ITER and DEMO), with additional 45 MW of heating power to load the divertor
- Test of different magnetic configurations (SN, DN, X-divertor, NT)
- HCD Systems based on consolidated technology
- Three-phase installation plan (each ~5 years), accordingly to the DTT Research Plan
- Integration challenges in the design and development of the HCD systems, assuring flexibility to support all the plasma configurations foreseen

Main Parameters			
R [m]	2.19	Pulse length [s]	100
a [m]	0.70	P_{TOT} [MW]	45
I_p [MA]	5.5	V_{plasma} [m³]	≈30
B_T [T]	6.0	P_{sep}/R [MW/m]	15
β_N	1.5	$<T_e>$ [keV]	6.1
n_e/n_G	0.42	$<n_e>$ [10^{20}m^{-3}]	1.8

System	Frequency / Energy	Phase / Installed Power	Engineering solution for Heating flexibility
ECH	170 GHz	P1 – 16 MW P3 – 32 MW	Front-steering launchers motion for central heating and MHD stabilization with indipendent poloidal and toroidal motion
ICH	60-90 MHz	P1 – 4 MW P3 – 8 MW	Movable antenna design to ensure effective coupling even with large plasma-antenna gaps
NBI	510 keV	P2 – 10 MW	Beam energy adjustability via PS steps of 200 kV to allow operation in low-density plasma and during current ramp-up/down phases

Indicative Comparison of electromagnetic loads

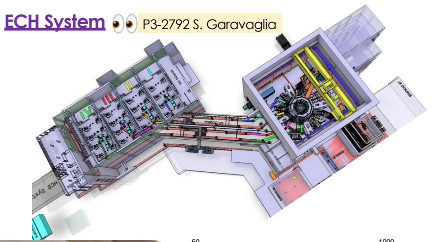
	B_0 (T)	I_p (MA)	R_0 (m)	a (m)	$I_p \frac{B_0 R_0}{R_0+a} \frac{1}{a^2}$
JET	3.4	5	2.96	1.25	7.6
AUG	3.2	1.4	1.65	0.5	13.7
JT60SA	2.25	5.5	2.96	1.18	6.3
EAST	3.5	1	1.85	0.45	13.9
KSTAR	3.5	2	1.8	0.5	21.9
ITER	5.3	15	6.2	2	15
DTT	5.85	5.5	2.19	0.7	49.7

- Challenge for movable items facing the plasma due to the mechanical constrains for the thermal loads and the forces induced by disruptions
- Comparison of the parameters playing the main role in the intensity of such forces:
  - I_p, local B_T, disruption time∝$1/a^2$

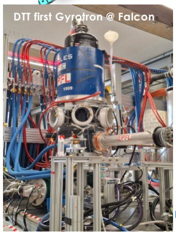
- DTT, with its compactness and high field/plasma current, is well above the level of e.m. loads in other tokamaks
- A proper and robust mechanical design of all movable part is required, with the exclusion of materials with high electrical conductivity or to set higher limits for tensile yield strength for the allowable materials
- In addition, the pulse length of DTT requires an accurate cooling of all components transmitting high power to plasma

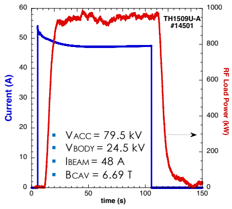
ECH System

P3-2792 S. Garavaglia



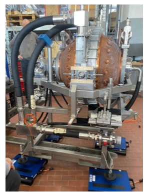
Parameter	Value
Frequency/Unit Power	170 GHz / 1 MW
Installed Power / Transmission Efficiency	32 MW / >90%
Plasma relative minor radius coverage	0-0.8 equatorial 0.2-0.85 upper
Toroidal Injection angle	±25° equatorial ±22.5° upper
Steering speed	20°/s, Δρ/dt = 0.6/s
Beam waist @ resonance	44.5 mm equatorial 32 mm upper
Power modulation	100% up to 5 kHz





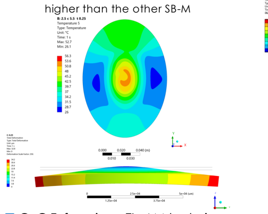
- Time evolution of the thermal power measurement and related I_{beam}

- Connection Line to direct the gyrotron output to the RF load

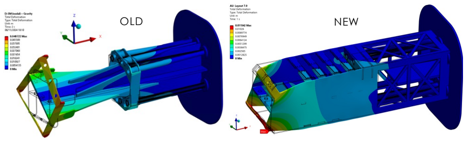


- FAT of the first RF Load in Curti Costruzioni Meccaniche

Combiner with thermal load 6 times higher than the other SB-M



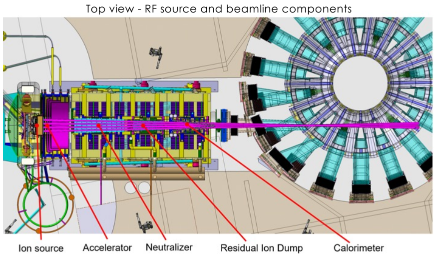
- CuCrZr for mirrors TL, AM technique
- Def. ~30 μm/<80 μm for SB/MB mirrors
- Total losses ~6.5% for ideal case (GRASP)



- Forces, moment reactions and max displacement, under the em loads generated during a vertical disruption event scenario
- Launchers supporting structures optimized: tot def. max 11.5 mm
- Insulation to be introduced to limit current loops (def. < 10 mm)
- Launching mirrors: efficient cooling, minimizing induced currents
  - High-thermal conductivity materials, with low electrical conductivity
  - Composite material under study, strong Nickel alloy as alternative

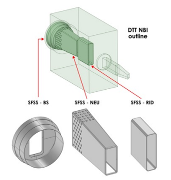
NBI System

Top view - RF source and beamline components



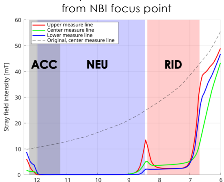
Parameter	Value
Injected Power	10 MW
Beam Energy	510 keV
Accelerated D^0 Current	40 A
Extracted D- Current Density	> 239 Am^{-2}
Pulse length	50 s
Overall Efficiency	0.357
Beamlet divergence	> 7 mrad

- Air insulated beam source, with ion source and accelerator connected to the VV
- Modular Multilevel Converter solution preliminarily explored

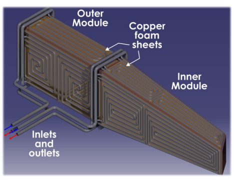


- SFSS scheme and ferromagnetic element composing it

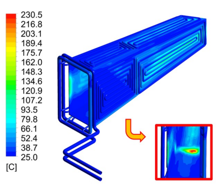
Stray field vs distance from NBI focus point



- Relevant stray vertical field impacting the overall efficiency and increasing heat loads on the main components
- Stray Field Shielding System developed, high efficiency kept
  - Negligible effect of the shielding on the plasma poloidal field
  - **EOF Instant:** max shield response field ≈ 0.35 G
  - **SOF Instant:** max field < 0.3 G

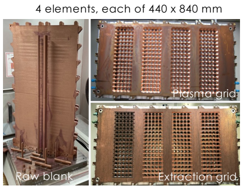


- Re-ionization due to presence of background gas, D⁺ deflected
- Double cooling spiral adopted, increasing the tubes density in the critical region



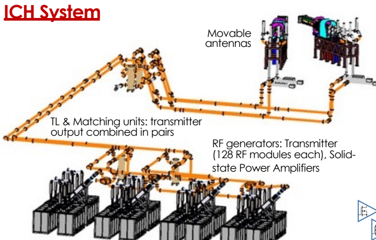
- Duct linear in CuCrZr, actively cooled (peak ~3 MW/m²)
- Temperature below critical values

4 elements, each of 440 x 840 mm



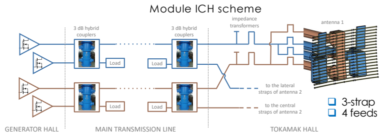
- CuCrZr in AM (laser powder bed fusion)
- Spherical shape for ion beam focusing
- Full-size finished Plasma & Extraction Grids printed (4x5x17 beam-lets)

ICH System



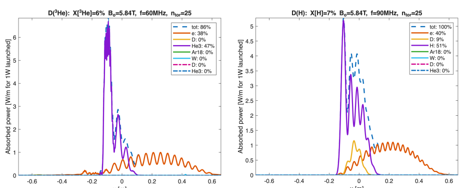
Parameter	Value
Frequency range	60-90 MHz
Installed Power	4.8 MW
Pulse length	50 s
Max available CW power	480 kW
Power to SN plasma	≥ 3 MW
Antenna power density	< 3 MW/m²

Module ICH scheme

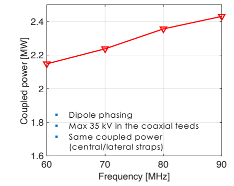


- 3-strap
- 4 feeds

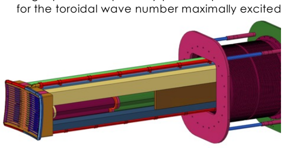
- First 2 transmitters: procurement to be completed by 2026
- Testbed realization on-site for TXI test: RF components and 2.5MW RF load procured



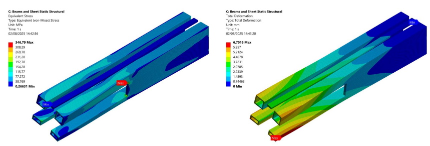
- Single-pass absorption by plasma species vs minor radius, predicted by TOMCAT, for the toroidal wave number maximally excited (^{3}He m. @60 MHz, H m. @90 MHz)



- Power coupling capability of the curved antenna model, calculated with TOPICA



- Antenna designed on the basis of the SN scenario
- Movable to couple power in a best-effort basis on the other magnetic configurations
- Semi plug-in concept, Antenna box installed by remote handling from inside (Faraday screen and limiters)



- Stress and deformation as calculated for the sustaining beams of the ICH Antenna for major disruption by CREATE
- Verification and optimization of the whole structure is on-going to keep deformation below 5 mm