OVERVIEW OF THE DESIGN AND PROCUREMENT OF ECRH SYSTEM FOR DTT

S. GARAVAGLIA[1], G. GRANUCCI[1,2], S. BERTOLAMI[3], M. BONESSO[4], A. BRUSCHI[1], B. BAIOCCHI[1], D. BUSI[5], A. CALAMIDA[6], M. DE NARDI[7], R. DIMA[4], F. DI PAOLO[3], F. FANALE[1], P. FANELLI[8], G. FAVERO[4,9], L. FIGINI[1], E. GAJETTI[10], A. MAISTRELLO[7], A. MORO[1], A. PAGLIARO[5], A. PEPATO[4], P. PLATANIA[1], P. REBESAN[4], M. RECCHIA[7,11], N. RISPOLI[1], A. SALVITTI[2], L. SAVOLDI[10], A. SIMONETTO[1], M. TURCATO[4], A. ROMANO[2,6]

[1]Institute for Plasma Science and Technology, National Research Council (ISTP-CNR), Milano, Italy
[2]DTT S.C.a r.l., Frascati, Italy
[3]University of Rome Tor Vergata, Department of Electronics Engineering, Roma, Italy
[4]National Institute for Nuclear Physics (INFN), Padova, Italy
[5]Department of Mechanical Engineering, Politecnico di Milano, Milano, Italy
[6]ENEA, Fusion and Nuclear Safety Department, C.R. Frascati, Frascati, Italy
[7]Consorzio RFX, Padova, Italy
[8]Department of Economy, Engineering, Society and Business (DEIM), University of Tuscia, Viterbo, Italy
[9]Department of Management and Engineering, University of Padova, Vicenza, Italy
[10]MAHTEP Group, Dipartimento Energia "Galileo Ferraris", Politecnico di Torino, Torino, Italy
[11]Institute for Plasma Science and Technology, National Research Council (ISTP-CNR), Padova, Italy

e-mail: saul.garavaglia@istp.cnr.it

Introduction- The Divertor Tokamak Test (DTT) [1] facility is under realization with the aim to explore solutions for the power exhaust towards the design of the future fusion power plant DEMO. For this reason, DTT will be equipped with one of the largest ECRH systems, with the power capacity increasing in three steps according to the machine development program: 16 units for the first phase (14.4 MW at plasma) that will be doubled with a total of 32 units for the third phase (28.8 MW at plasma or more by utilizing higher-power units if available). The schedule is based on the development of an ECRH system structured into four clusters, each consisting of 8 gyrotrons and relative Power Supplies (PS), located in a building 80 m from the tokamak hall. These sources are connected to the DTT tokamak through a single/multi-beam evacuated Quasi-Optical (QO) Transmission Line (TL) installed on a bridge and two launching antennas positioned in the equatorial and upper ports of the same vacuum vessel sector. The system is primarily designed for localized plasma heating and current drive while its high flexibility also supports various functions throughout the plasma pulse, such as the stabilization of Neoclassical Tearing Modes (NTM), as outlined in [2]. Dedicated studies have been performed regarding the EC beam characterization aimed at verifying the fulfilment of the several tasks foreseen for the different operational phases of the machine and during the various phases of the discharges. Additional work has been carried out in order to assess the EC radiation not absorbed by the plasma to find the load on the first wall due to unabsorbed RF power at to give a first evaluation of the background stray radiation impacting on diagnostics.

Launcher: launcher structure has been analysed for induced currents during Major Disruptions (MD) and Vertical Displacement Events (VDE). High magnetic currents in the front part of the structure (where static magnetic field is above 4 T) causes high forces and torques inducing deformation and stresses above limits, in particular on the fixed mirrors in copper alloy. The deformations on the structure can be reduced by minimising horizontal plate extension in the high-B field zone and increasing stiffness with cage-type structure avoiding current loops. Design of launcher mirrors has been improved to reduce electromagnetic forces and thermal stresses due to microwave heating.

Transmission Line: the conceptual design of the QO TL has been finalized and prototyping of the mirrors is now underway. Additive manufacturing techniques are being utilized to realize optimized cooling circuits designed to withstand and efficiently manage highly localized thermal loads. The TL layout has been analyzed using electromagnetic tools under ideal conditions, perfect alignment and undistorted mirror surfaces, to evaluate the target transmission efficiency of over 90%. In parallel thermo-hydraulic and structural analyses of mirrors cooling were conducted to minimize deformations. These deformed surfaces were then incorporated into a complete electromagnetic model to assess performance reduction due to non-idealities, revealing an increased microwave stray radiation and finally the reduction in the fractional power coupled with the ideal TEM_{00} Gaussian mode. The design of the polarizers also requires special attention due to the extremely high peak thermal load, reaching up to 8 MW/m². To mitigate this, a cooling solution based on Triply-Periodic Minimal Surfaces was selected, significantly increasing the wetted surface area and fluid turbulence while maintaining a low pressure drop.

Gyrotron & Power Supply: the source specifications have exploited the ITER gyrotron project and for this reason a joint open and international procurement with the F4E was initiated, ultimately awarding Thales as the gyrotron supplier for DTT. Each gyrotron delivers 1 MW of power at 170 GHz for 100 s, with an efficiency larger than 40%. The first DTT gyrotron has been manufactured and tested at the FALCON facility, confirming compliance with frequency, pulse length, output power and efficiency requirements. Based on this, the contract for manufacturing the next 15 gyrotrons has been started to complete the supply for the first phase of DTT. Each pair of gyrotrons is powered by a High Voltage Power Supply (HVPS) set, composed of a Main Power Supply (MPS) that feeds both gyrotrons in parallel and two Body Power Supplies (BPS), each individually dedicated to a single gyrotron. The MPS is rated at -60 kVdc and 110 A (2 × 55 A), negatively polarizing the cathode relative to the collector to supply the primary power to the electron beam. Meanwhile the BPS operates at 30 kVdc and 100 mA, positively polarizing the body electrode. The HVPS system is designed with fast output voltage dynamics, including ramp-up and ramp-down times of up to 50 µs / 30 µs for the MPS / BPS respectively to minimize the excitation of competing RF modes during voltage increases. A stringent settling time of under 20 µs ensures a stable flat-top voltage, enabling effective modulation at frequencies of up to 5 kHz. A short evacuated Connection Line (CL), designed to direct the gyrotron output to the RF load and accommodate various mirrors, has been realized for use at the FALCON. The CL will utilize the DTT pre-series gyrotron to validate both the mirror design for the TL and the associated manufacturing techniques. Additionally, the procurement of 4 RF loads is currently in progress.

Control System: The ECRH plant's control system is structured as a network of Plant Systems Unit (PSU), which act as interfaces between the central CODAS and the Plasma Control System (PCS) with the individual subsystems. These PSUs standardize interactions, hiding low-level implementation details while ensuring a uniform control interface across all components. Each PSU comprises three core elements: the Slow Control Unit (SCU), Fast Control Unit (FCU), and Fast Alarm & Safety Unit (FA&SU). Each gyrotron cluster is organized with four PSU, each managing a paired gyrotron and launcher units, with an additional PSU dedicated to control and monitor the multibeam TL.

REFERENCES

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