IFMIF-EVEDA RF POWER SYSTEM

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Abstract

The IFMIF/EVEDA Accelerator Prototype will be a 9MeV, 125mA CW deuteron accelerator to validate the technical options for the IFMIF accelerator design. The Radiofrequency Quadrupole (RFQ), buncher cavities and Superconducting Radiofrequency Linac (SRF Linac) require continuous wave RF power at 175 MHz with an accuracy of ±1% in amplitude and ±1º in phase. Also the IFMIF/EVEDA RF Power System has to work under pulsed mode operation (during the accelerator commissioning). The IFMIF/EVEDA RF Power System is composed of 18 RF power generators feeding the eight RFQ couplers (200kW), the two buncher cavities (105kW) and the eight superconducting half wave resonators of the SRF Linac (105kW). The main components of each RF power chain are the Low Level Radio Frequency system (LLRF), three amplification stages and a circulator with its load. For obvious standardization and scale economies reasons, the same topology has been chosen for the 18 RF power chains: all of them use the same main components which can be individually tuned to provide different RF output powers up to 200kW. The studies and the current design of the IFMIF/EVEDA RF Power System are presented in this contribution.

MAIN DESCRIPTION

The RF Power System combines three groups of components that will be integrated in the Accelerator Prototype Building in Rokkasho (Japan):

- RF Modules
- RF Final Amplifier Anode Power Supplies
- Auxiliaries for the installation at Rokkasho (RF Local Control System, Coaxial Transmission Lines, Water/Air Cooling System)

The first 200kW RF chain ("the Prototype RF Chain") will be installed in Madrid and extensively tested to demonstrate its full capabilities. The Prototype RF Chain will be permanently available during the complete duration of the project at the Spain Test Platform and it will be also used for the testing and conditioning of the SRF Linac couplers.

The first complete RF Module manufactured will be delivered for installation at the France Test Platform, in order to test the accelerator RF components at high power. Later on, it will be transferred to Rokkasho to feed the SRF Linac.

RF MODULE

The RF Module original concept is to assembly two complete amplifying chains in a unique module. This approach allows the reduction of the time needed for the installation at Rokkasho (RF Modules will be shipped fully assembled) and eases the commissioning and maintenance operations in the Accelerator Building (RF Modules can be extracted partially or totally from their operating position). For the future IFMIF plant this design will reduce the accelerator MTTR by having spare RF modules, leading to a better availability.

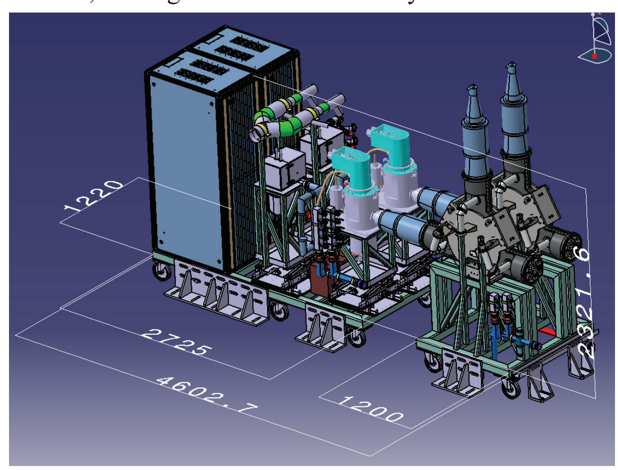

Figure 1: RF module.

RF Module Platforms

The RF Module has been designed with two different and separated platforms in order to increase the maintainability:

- A main platform used for racks and RF power amplifiers, so the higher failure probability components are located in a lighter structure easy to move.
- A secondary platform used for circulators and their loads, so the heaviest components are located in another platform with a lower maintenance probability.

All main platforms will be the same and the circulators platforms will have two different configurations depending on the RF Module nominal output power:

- 200kW RF chains: 250kW circulator / 50kW load
- 105kW RF chains: 135kW circulator / 50kW load

The platforms mechanical structure is being developed by TTI (Spain). It has been designed in order to avoid natural resonances below 80Hz that can damage the tetrodes. The platforms will be manufactured in carbon steel and the tube amplifiers will be mounted in specially designed 3 degrees of freedom benches.

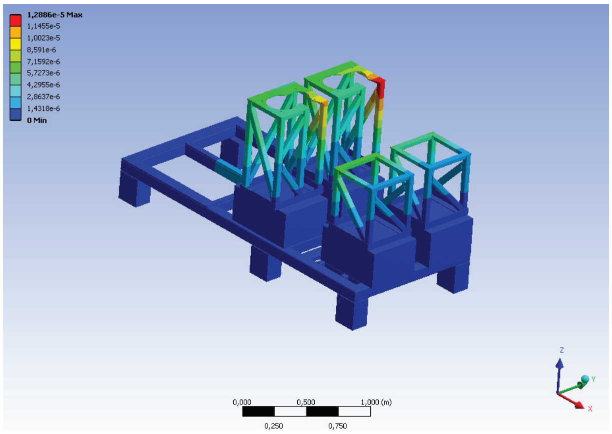

Figure 2: Main Platform Vibration Analysis

RF Module Racks

The two RF Module racks will contain the Low Level RF (LLRF), the Module Control System (PLC), the RF Pre-drivers (Solid State) and all the power supplies needed for the four tetrodes (except the RF Final Amplifier Anode Power Supplies that will be installed nearby). The components weight has been distributed inside the racks to have a well balanced RF Module with the lowest possible gravity center.

RF Pre-driver Amplifiers

The first amplifying stage of the RF chain have been designed and manufactured by Europeenne de Telecommunications S.A. (France) and it is based on solid state technology. The tests at factory have been successfully passed for the first unit in September 2010 and all the units needed have been delivered to Ciemat. It has a maximum output power of 500W and a gain of 64dB to amplify the output power of the LLRF up to the needed power to drive the next amplifying stage.

RF Driver Amplifiers

The second amplifying stage of the RF chain is being manufactured by Thales Electron Devices (France) and it is based on the TH18526C cavity and the TH561 tetrode. The first two units have been successfully tested at the beginning of October 2010. Eight units have been already delivered to Ciemat. It has a maximum output power of 16kW, requiring 280W of drive power.

RF Final Amplifiers

The last amplifying stage is based on the TH781 tetrode manufactured by Thales Electron Devices (France). The RF Final Amplifier cavity and auxiliaries have been designed and are being manufactured by Iba Group (Belgium). The first two TH781 tetrodes passed the factory tests successfully in June 2010. And the first RF Final Amplifier unit has been tested (low RF power) with a TH781 tetrode at Iba premises in May 2011. This unit will be shipped to Ciemat in October 2011 and the high power tests will be performed in the beginning of 2012 at the Spain Test Platform with the Prototype RF Chain.

RF Module Power Supplies

The Genesys family from TDK-Lambda (Japan) with an output power range from 750W to 15kW have been chosen practically for all the required power supplies to be installed inside the RF Module racks. Except the TH-561 anode power supply which is from the ALE 203/303 family of the TDK-Lambda high voltage products division.

After analyzing the electromagnetic noise environment and other working conditions, some modifications have been designed for these power supplies (AC input line filters, galvanic isolation, chassis shielding, and digital communication interface isolation).

Tetrodes Protection System

The Tetrodes Protection System has to protect the driver and final amplifier tubes from damage caused by excessive voltages or current peaks caused by arcs between electrodes. This system has to protect tubes in any operation mode and independently of the RF Module Control System. The main components of this system are the following:

- Screen grid protection circuit: includes bleeder resistors to avoid the screen grid auto-polarization and spark gap to protect in case of overvoltage.
- Control grid protection circuit: bleeder resistors, spark gap and additionally, this grid is protected against reverse current (tube internal arc). The reverse current is limited by a protective resistor bypassed by diodes which should withstand a few kilovolts inverse voltage in case of arcs.
- Anode protection circuit: a very reliable over current protection is used. In case of an arc, the HVPS should be switched off in a time less than 20ms but even in this case, the energy stored in the output filter and in the stray cable capacitance could damage the tube. For that reason a crowbar will be used in order to short circuit the anode power supply.

RF Module Control System

The RF Module Control System is based on a Simatic S7 PLC which will monitor and control all physical parameters within each RF Module. This control system manages more than 300 input/output signals and has the following interfaces:

- RF System (LLRF, RF amplifiers, RF switch, …)
- RF Water/Air Cooling System
- RF Module Power Supplies
- 400kW HVPS Control System
- Tetrodes Protection System
- RF Local Control System

The RF Module Control System is being developed by Indra (Spain). All the sequences for the RF chains start up and shut down have been designed including intermediate/error states and their transitions.

For the shut down sequence, if one of the control devices (LLRF, PLC, water cooling-PLC…) detects an error (arc, HW or SW fail…) that implies abnormal operation, I/O interlock signals will trigger the tetrodes protection system to initiate the appropriate shut down sequence, avoiding any damage to the tubes.

Circulators and Loads

The circulators are being manufactured by AFT Microwave GmbH (Germany) and the first 250kW circulator unit will be delivered in December 2011. The insertion losses will be better than 0.3dB and the isolation between ports will be higher than 20dB.

The circulator loads are being manufactured by Spinner GmbH (Germany) and the first two 50kW units have been delivered to Ciemat.

RF Module Cooling

The water distribution in the RF Modules is a loop with one inlet/outlet to be connected to the RF Water Cooling System main distribution pipes in the accelerator building, which is the responsible for water conditioning and pumping. The circuit is balanced using automatic flow regulators positioned at the returning branches to assure the desired flow rate. Individual temperature and flow rate sensors are used to monitor the components cooling. Also at the inlet of the loop there are conductivity, pressure and temperature sensors to guarantee the water quality in each RF Module.

A distributed solution has been designed for the air cooling so one 11kW high pressure centrifugal blower will be used to feed each RF Module. The distribution system inside the module includes pressure regulators, filters, flow rate switches and pipes.

RF FINAL AMPLIFIER ANODE POWER SUPPLY

The RF Final Amplifier Anode Power Supply main components are:

- Breaker installed outside the Accelerator Prototype Building
- Step down transformer (outdoor)
- 400kW High Voltage Power Supply installed in the RF Power Bay area of the Accelerator Building.

Taking into account the requirements from the different accelerator cavities, this power supply have been designed with enough power to feed one RFQ final amplifier anode or two SRF LINAC final amplifiers anodes (simultaneously).

Breaker

The breaker function is to connect and to disconnect each RF Final Amplifier Anode PS to the 6.6kV Japanese network under nominal conditions. It will interrupt the current in case of a malfunctioning or if an external order requires it. It also has enough interrupting capacity for the opening in case of short-circuit. It will be encased in a cabinet with IP54 environment protection level for outdoor operation.

Step-down Transformer

It is a three phase transformer with double secondary winding that reduces the 6.6kV network voltage to the 500V needed by the HVPS. It is rated for outdoor operation and it is oil cooled.

400kW HVPS

The 400kW HVPS is being manufactured by GreenPower Technologies (Spain) and has been designed with three main power stages (see Figure 3).

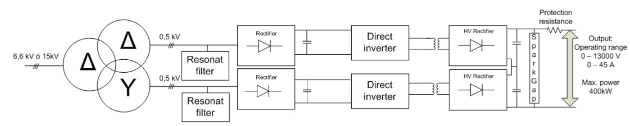

Figure 3: Main HVPS topology.

First is a 12-pulse non-controlled rectifier operating at 500V. The second stage is composed of two H-bridge inverters for the voltage output control. Then, each inverter output is connected to a HV transformer of a non-controlled rectifier. Finally, the two DC outputs are connected in series. The control system based on FPGA/DSP measures the voltage on the output terminal of the source and generates an error signal acting directly over the inverter in order to reach a voltage set point. Special care has been taken designing the HVPS in order to fulfil the accelerator requirements under pulsed modes condition. The Table 1 shows the HVPS specification for the pulsed modes.

Table 1: HVPS Pulsed Modes

Pulse Width	Maximum Frequency	Maximum Duty Cycle
$W \leq 1ms$	10 Hz	-
$1ms < W \leq 100ms$	2 Hz	-
$W > 100ms$	1 Hz	80%

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