RF POWER SYSTEM FOR THE IFMIF-EVEDA PROTOTYPE ACCELERATOR

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Abstract

The IFMIF-EVEDA accelerator will be a 9 MeV, 125 mA CW deuteron accelerator prototype to validate the technical options of the accelerator design for IFMIF. The RFQ, buncher cavities and superconducting Half Wave Resonators of the DTL must be fed with continuous RF power at 175 MHz frequency with an accuracy of 1% in amplitude and ±1º in phase. The RF power system consists of several amplification stages, which are based on RF vacuum tubes. The main characteristics of the RF system and of the high voltage power sources required to feed the anodes of the high power tubes are presented in this paper.

INTRODUCTION

The IFMIF-EVEDA accelerator will be a 9 MeV, 125 mA CW deuteron accelerator prototype to validate the technical options of the accelerator design for IFMIF. The main components of the accelerator are the ion injector, the Radio Frequency Quadrupole (RFQ), the matching section, the Dift Tube Linac, the beam transport line and the beam dump.

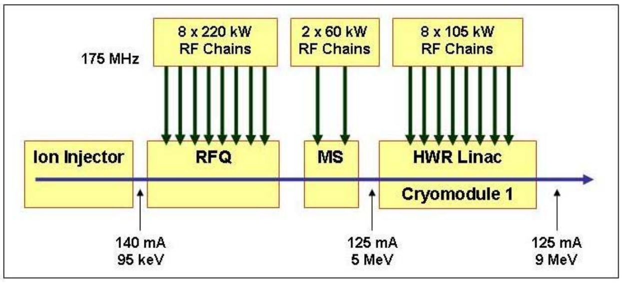

Figure 1: RF power requirements of the IFMIF-EVEDA Prototype Accelerator.

The superconducting proposal, based on Half Wave Resonators (HWR) and replacing the room temperature Drift Tube Linac, was finally selected for the EVEDA phase [2]. This proposal also revised the RF system, and relies on smaller power units, based on more conventional RF tubes than the ones foreseen at the beginning: 8 units of 105 kW for EVEDA (and 18 units of 105 kW and 24 units of 220 kW for each accelerator of the final IFMIF) using tetrodes instead of diacrodes of 1 MW each. As a positive side effect, the 220 kW units will also be used for the RFQ, standardizing the whole accelerator. In addition, such power units can feed the buncher cavities of the matching section.

The RF power system consists then of 18 power amplifiers (Figure 1) feeding the RFQ, the buncher cavities and the Half Wave Resonators. While the 8 amplifiers of the RFQ must be phase-locked for a proper excitation of the RFQ cavity, the fields of the superconducting cavities are better controlled by the use of individual RF sources. For obvious standardization and scale economies reasons, a similar topology has been chosen for the 18 RF chains: all of them use the same main components but each of them can be individually adjusted to deliver any value of RF power from 60 kW to 220 kW.

RF POWER AMPLIFIER CHAIN

Each of the eighteen required chains for the accelerator prototype is based on several 175MHz amplification stages. The main components of each chain are the LLRF (Low Level Radio Frequency) system which has to manage the RF driving signals to the amplifiers, three amplification stages and a circulator. Finally the required RF power is transferred to the RF couplers via a coaxial line (Figure 2).

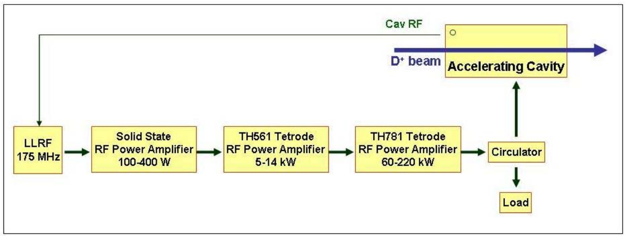

Figure 2: RF Power Amplifier Chain.

Low Level RF

The primary role of the Low Level Radio Frequency electronics (LLRF) is to control the amplitude and the phase of each cavity (fast regulation) and to control the tuning of each cavity to keep its resonant frequency close to the accelerator operating frequency. The IFMIF-EVEDA LLRF system has to work under CW mode operation and it has also to support pulse mode operation (during the commissioning and tuning of the prototype accelerator). The main requirements of the LLRF system are listed below:

- Field error ± 1% in amplitude, ±1deg. In phase.
- Field ramp up with a predefined time profile.
- Switch off the RF power in case of abnormal operation or upon request from other subsystem.
- RF signals monitoring to control performance and prevent failures.

Pre-Driver Amplifier

The pre-driver needs to provide about 400W RF power to the next driver. For this power level, a solid state technology can be selected.

Driver Amplifier

The driver amplifier is based on a tetrode and the operating conditions are listed below:

- RF Output power ≤ 20 kW
- RF Input power ≤ 500W
- Anode voltage max. 6 kV
- Anode current max. 4 A

Final Amplifier

The final step of the amplifier chain is also based on a tetrode and the operating conditions are listed below:

- RF Output power ≤ 220 kW
- RF Input power ≤ 15 kW
- Anode voltage max. 12 kV
- Anode current max. 30 A

The output power of the RF chain can be adjusted to the level needed for the right operation of the accelerator by changing the parameters of the power supply of the driver and of the final amplifier.

The circulator and dummy load are designed to protect the final amplifier from the reflected RF energy and will be also used during the RF system commissioning. The RF power from the circulator to the cavity coupler will be transmitted by coaxial rigid lines. The type of the coaxial lines depends on the output power to be transmitted. Preliminary calculations show that EIA 6"1/8 coaxial lines can be used to supply buncher cavities and linac cavities (RF power between 60 kW and 105 kW) and EIA 9"3/16 coaxial can deliver 220 kW RF power to the RFQ couplers.

REMOVABLE RF POWER MODULE

In order to optimize space, maintenance and availability, a symmetric modular system composed by removable modules with two complete amplifier chains each, is then proposed. Each of these modules is a removable board containing the following components (Figure 3):

- Two 105 or 220 kW amplifiers
- The corresponding driving amplifiers with solid state pre-drivers
- Anode filters for both HVDC lines
- A rack for auxiliary power supplies (for screen grid, control grid and filaments) and control systems
- An interconnection rack
- Fast connections for cooling circuits
- Fast connections for electrical feeding (HV and LV)
- Easy connection for coaxial transmission lines
- Circulators and dummy loads

All electrical and cooling interconnections with the amplifier module will be located on its front side to allow easy disconnection. Within the interconnection rack, the HV connection will be at the top, followed by the LV electric connection and finally the air and water cooling connections will be at the bottom. Moreover, the control boards for the electronic equipment and power supplies are also accessible from the front side. In case the tetrode cavity requires fine mechanical adjustments during the tuning and commissioning, the possibility of using a system based on step motors will be studied to allow adjustments from the front of the module. However, the RF interface with the rigid coaxial lines will be at the back of the module.

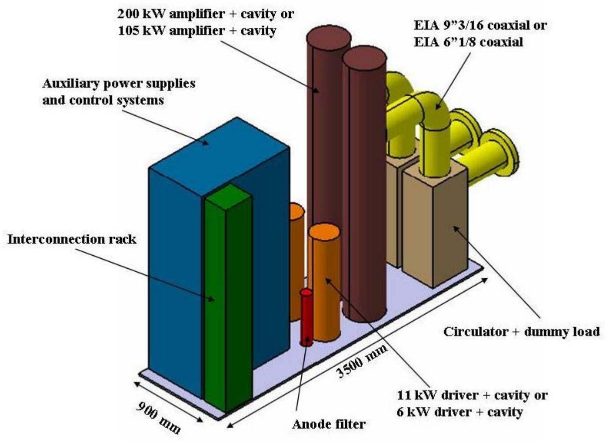

Figure 3: Removable RF power module

ANODE HVDC POWER SUPPLY

The anode HVDC power supplies should be able to feed the RF amplifiers which have different levels of the output power:

- 8 x 220 kW for the RFQ
- 8 x 105 kW for the HWR
- 2 x 60 or 105 kW for the buncher cavities

A possible solution is to use two types of HVDC power supply. One of them should have enough DC power to supply one RFQ amplifier of 220 kW or two HWR amplifiers of 105 kW.

Various solutions can be used for the anode HVDC power supply. The conventional configuration consists of the following elements:

- step down transformer
- three phase thyristor voltage regulator
- step up transformer
- rectifier, non-controlled

The deficiencies of this topology are the high level of harmonics at the output voltage and the relatively low power factor.

Another type of HVDC power supply relies on the IGBT switching technology. This power supply consists of a 12 pulse thyristor rectifier with a capacitor bank which feeds a certain number of switching modules. Each module is equipped with an IGBT inverter (2-5 kHz frequency), a single-phase step up transformer and a diode rectifier. The number of modules in series depends on the output voltage value. The Pulse Width Modulation (PWM) control system can support a phase shift between the modules, resulting in a low level harmonic content in the output voltage. This type of power supply allows also a fast and precise output voltage regulation and a fast switch off in case of malfunction.

Another possible solution within the switching technology, is based on the use of a multi-secondary winding transformer that feeds rectifiers whose outputs are connected in series. The total HVDC output voltage of the power supply is obtained by adding the smaller DC outputs of the rectifiers.

A comparison study, in terms of performances and costs as well, will allow to select the best solution.

CONCLUSIONS

The RF power system for the IFMIF-EVEDA Prototype Accelerator consists of 18 removable modules with identical mechanical structure and main RF power and electronics components. This solution allows to optimize space, maintenance and availability of the system. The anode HVDC power supply based on IGBT switching technology enables to adjust the RF output power of each module between 60 kW and 220 kW.

REFERENCES

[1] IFMIF Comprehensive Design Report, An activity of the International. Energy Agency, January 2004.

[2] A. Mosnier, A. Ibarra and A. Facco, “The IFMIF-EVEDA Accelerator Activities”, these proceedings.

[3] M. Weber, P. Mendez, I. Kirpitchev, M. A. Falagan, A. Ibarra. El Sistema de Radiofrecuencia de IFMIF. Laboratorio Nacional de Fusión, CIEMAT. Sociedad Nuclear Española. 2007