DESIGN PROGRESS OF THE RF SYSTEM FOR EMMA AT DARESBURY LABORATORY*

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Abstract

EMMA (Electron Model for Many Applications) is a non-scaling Fixed Field Accelerating Gradient (NS-FFAG) accelerator presently in the process of being built at Daresbury Laboratory as a proof of principle demonstrator for proton/carbon therapy application. Its aim is to take an injected beam from ALICE (Accelerators and Lasers in Combined Experiments) at 10MeV and accelerate it to 20MeV, so that the characteristics of NS-FFAGs can be studied. The beam is to be accelerated by 19 identical 1.3GHz RF cavities, which each need to provide the same accelerating voltage to the beam. The initial design stage of the RF system design has been completed, utilising three commercial suppliers of the major RF sub-system components.

INTRODUCTION

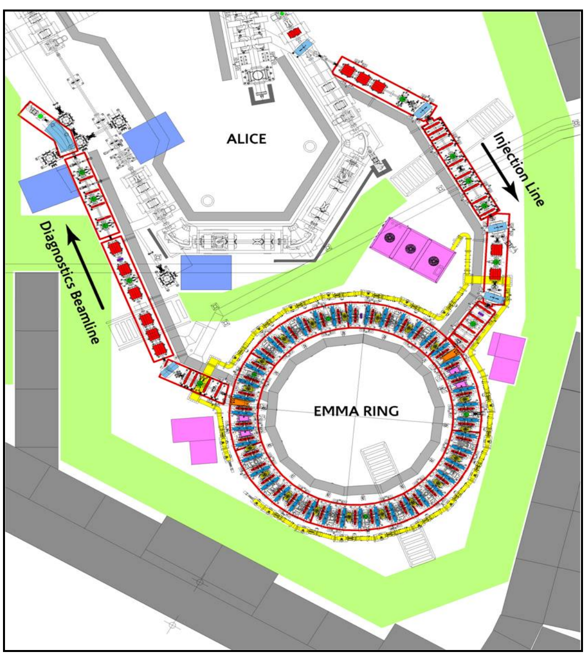

Figure 1: EMMA layout.

EMMA is a compact accelerator of 5.3 m diameter (Fig.1). The RF acceleration system for EMMA consists of 19, 1.3 GHz identical normal conducting RF cavities, which are distributed evenly around the 42-cell machine, with two cavities removed to allow access for the beam injection and extraction lines.

Each of the RF cavities has to be able to provide an acceleration of up to 180 kV (baseline requirement is only for 120 kV), and have the ability to operate over a frequency range of 5.5 MHz under the conditions defined in Table 1 below.

Table 1: EMMA Machine Parameters

Machine Parameters	Values	Units
Frequency	1.3	GHz
Frequency range	-4.0 to 1.5	MHz
Number of straights	21	
Number of cavities	19	
Total acceleration per turn	2.3	MV
Upgrade acceleration per turn	3.4	MV
Beam aperture	40	mm
RF pulse length	1.6	mS
RF repetition rate	1 to 20	Hz
Amplitude control	0.3	%
Phase control	0.3	°

The operating parameters for EMMA RF system are shown in Table 1and the system consists of 3 major sub-systems; a high power RF amplifier system, a RF distribution system and a low level RF (LLRF) control system. The RF system has to initially be capable of providing 3.6 kW per cavity (68.4 kW in total) and have the ability to be upgraded to 8.1kW per cavity (153.9 kW in total). Additionally, the system has to be able to maintain precise amplitude and phase control during operation. The design concept for the EMMA RF system was reported elsewhere [1], with an RF requirement to provide an additional 30% above the defined level, so as to allow for any distribution losses and to build in some power overhead. Since then a tender exercise has been completed for the high power amplifier and RF distribution systems, and the designs have been finalised. Fabrication of these systems is now well under way.

RF CAVITY

Due to the compact nature of the EMMA ring, the length of the cavities was restricted to 110 mm from flange to flange, which along with the large 40 mm beam aperture meant that to obtain the maximum accelerating gradient of 180 kV, the Q of the cavity had to be as high as practically achievable [2].

A contract was therefore placed with Niowave Inc. to manufacture and deliver 20 RF cavities (1 spare). At the present, 16 cavities have been delivered, with the final 4 awaiting the delivery of the coaxial input couplers. Response measurements performed show that the cavities have a tuning range of the order of 10 MHz, which is well in excess of the 5.5 MHz initially specified. The LLRF

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system will be used to set the required frequency of the cavities via a motor drive on the tuner system.

HIGH POWER RF AMPLIFIER SYSTEM

The contract to provide the high power RF amplifier system was awarded to CPI. The VIL409 high power RF amplifier system (Fig. 2) comprises of 3 x 19 inch racks, which include a CPI Inductive Output Tube (IOT) model CHK51320W, a high voltage power supply (HVPS), ancillary power supplies, and a 1 kW solid state RF amplifier from Bruker that provides RF drive to the IOT. The high power RF amplifier is provided with a 1.3 GHz RF signal at 0 dBm that has a 1.6 mS pulse at a pulse repetition frequency (PRF) from 0 to 20 Hz. The gain of the solid state amplifier is typically 61.8 dB and the IOT gain is typically greater than 21 dB.

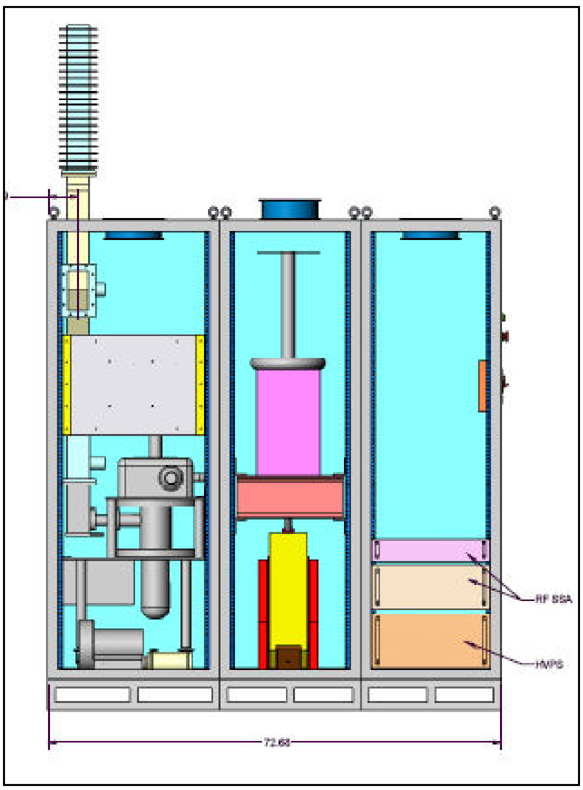

Figure 2: CPI high power RF amplifier layout.

Incorporated within the HVPS system will be a microprocessor-based controller, which will accept command inputs and provide status outputs to the front panel of the high power RF amplifier as well as the higher level EMMA control system and the low level RF (LLRF) controller.

The IOT is similar in design to one already being employed on ALICE, but has been adapted to meet the higher output power and larger bandwidth requirements of EMMA. CPI have evaluated the IOT under pulsed conditions and have achieved power levels in access of 100 kW as shown in Table 2, where the beam voltage was increased for a constant grid voltage of 105 V and a constant drive power of 663 W. This meets the required specification of 90 kW for the EMMA baseline design and will also meet the corresponding upgrade requirements of 200 kW with the addition of a second high power RF amplifier. Tests were performed to ensure that 90 kW can be achieved across the frequency range required. Figure 3 shows that for 1.29965 GHz a drive power just in excess of a 1000 W will be required.

Table 2: CPI IOT Characteristics

Beam Voltage (kV)	Beam Current (A)	Output Power (kW)	Efficiency (%)	Gain (dB)
40	3.42	82.0	59.9	20.9
41	3.48	86.1	60.3	21.1
42	3.52	90.0	60.9	21.3
43	3.60	93.6	60.5	21.5
44	3.64	98.6	61.6	21.7
45	3.70	103.8	62.3	21.9

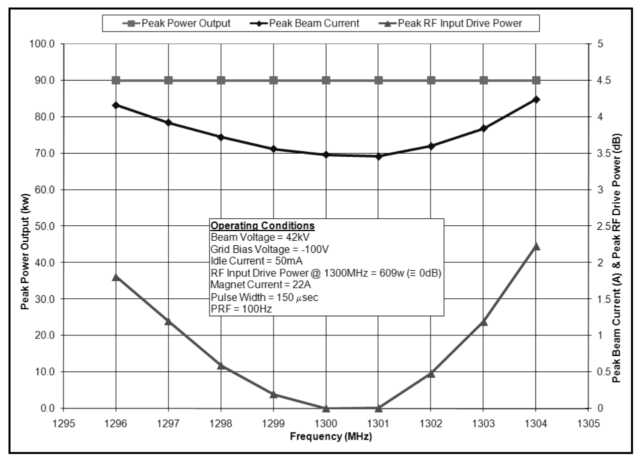

Figure 3: IOT bandwidth characteristics.

In line with the drive requirements for the IOT, CPI has tested the Bruker solid state RF amplifier (BLA1500 RF SSPA) under pulsed conditions up to 1.8 kW, without significant levels of gain compression.

A large part of the software programming is delayed due to the fact that it can only be done once the high power system is operating. However, good results have been achieved that show that the status reporting is near a "real-time" rate.

The delivery of the system to Daresbury Laboratory is anticipated to be early July 2009. Each of the racks will be positioned separately and then the necessary connections made in situ.

RF DISTRIBUTION SYSTEM

A number of RF distribution systems were investigated during the tender process. A design by Q-Par Angus was settled upon as shown in Fig. 4. The RF waveguide distribution system incorporates 17 hybrid and phase shifter waveguide modules, which are used to split the RF power in a cascade configuration. The power is initially split clockwise and anti-clockwise with a 3dB hybrid (10 and 9 cavities) and then the percentage of coupled RF power is increased along the distribution string (away from the source), so as to ensure that equal RF power levels are delivered to each of the 19 RF cavities.

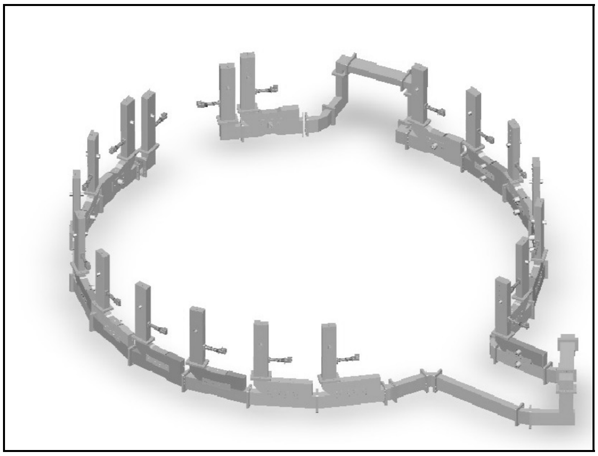

Figure 4: Waveguide distribution system.

The initial section of the waveguide system from the IOT to just beyond the hybrid splitter is in WR650, after which it is transformed to WG5Q waveguide. The initial split in RF power allows for a second high power amplifier system to be added at a later date if necessary, should the EMMA RF system is upgraded to higher power levels.

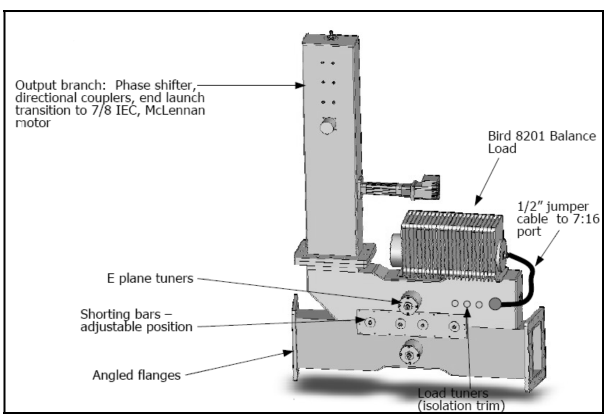

Figure 5: Q-Par angus hybrid and phase shifter waveguide module.

The hybrid uses a H plane coupling method and have a capacitive E plane tuner, so as to give the required power split. The phase shifter incorporates an RF short circuit piston that changes the guide wavelength and phase by altering the cut-off frequency, thus providing 180º of phase change. Production of the hybrid and phase shifter waveguide modules (Fig. 5) is well advanced with the first four modules having been set and validated for full operation. Delivery of the completed system to Daresbury Laboratory is anticipated by the end of May 2009.

LLRF DISTRIBUTION SYSTEM

To ensure the stabilisation of the accelerating field inside the EMMA RF cavities, the RF system will be controlled using a LLRF control system, which will include the hardware and software to optimise the amplitude and phase during operation and for the frequency of operation to be set. To perform this task the LLRF system will be monitoring and controlling the RF power levels within the RF system. These include the RF power levels to:

- each of the cavities via a pick loop in the cavity,
- the forward and reverse directional couplers on each of the hybrid and phase shifter waveguide modules,
- the forward and reverse power levels from the IOT, before and after a circulator,
- the forward and reverse power levels from the solid state driver.

The LLRF system must be capable of monitoring and controlling the high power RF system (amplifiers, waveguide system and cavities) so as to ensure the stabilisation of the accelerating field inside the EMMA RF cavities.

A contract has yet to be placed for the LLRF system, however the specification for the complete system has been defined and a request for tender will be issued shortly. However, LLRF tests have been performed using 2 EMMA RF cavities with the power split equally into each cavity via a 3 dB hybrid and phase shifter waveguide module provided by Q-Par. The results from the tests to date look very promising, with amplitude stability of 0.006% (specification is 0.3%) and phase stability of 0.0093º (specification is 0.3º) at a power level of 5 kW into each cavity. The results from these tests are reported in a separate paper at this conference [3].

SUMMARY

The designs for the high power RF amplifier system and the RF distribution systems have been finalised and production of the systems are well under way. Additionally the requirements for the LLRF system have been fully defined and it is anticipated that it will be possible to have the complete EMMA RF system available by early September 2009 so as to allow commissioning of the system before EMMA beam commissioning commences in early November 2009.

REFERENCES

[1] C.D.Beard et al, "RF System Design for the EMMA FFAG", EPAC 2008, Genoa, p. 3377.
[2] C.D.Beard et al, "EMMA RF Cavity Design and Prototype Testing at Daresbury", EPAC 2008, Genoa, p. 3374.
[3] C.D.Beard et al, "High Power RF Testing of the EMMA RF System", TU5PFP094, PAC 2009, Vancouver.