THE EMMA LLRF SYSTEM AND ITS SYNCHRONISATION WITH ALICE

A. Moss, S. Jamison, P. McIntosh, A. Wheelhouse ASTeC, STFC, Daresbury Laboratory, Warrington, UK, B. Baricevic, Instrumentation Technologies, Slovenia

Abstract

The Low Level RF (LLRF) control system on EMMA (Electron Model for Many Applications), the world's first Non-Scaling Fixed Field Alternating Gradient (NS-FFAG) accelerator is presently being installed and commissioned at Daresbury Laboratory. The LLRF system is required to synchronize with ALICE (Accelerators and Lasers in Combined Experiments) its injector, which operates at 1.3GHz, and to produce an offset frequency as required (+1.5 Mhz to -4 MHz) to then maintain the phase and amplitude of the 19 copper RF cavities of the EMMA machine. The design and commissioning of the LLRF system is presented.

INTRODUCTION

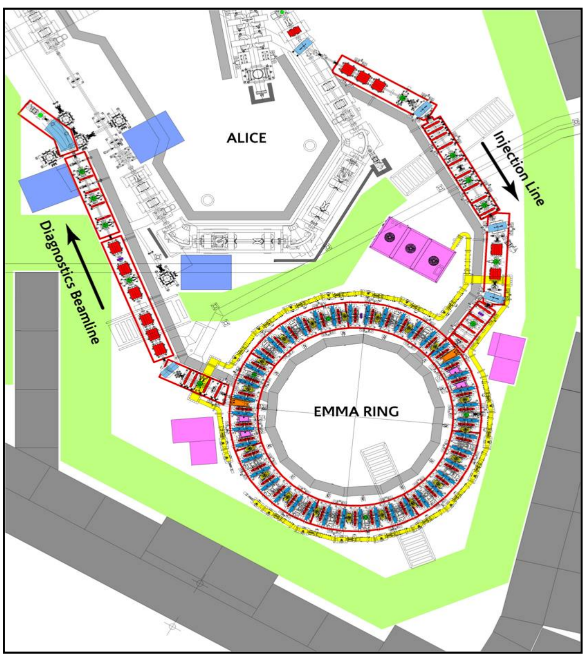


Figure 1: EMMA Layout.

Table 1: RF design parameters for EMMA

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	°

EMMA [1] is a prototype non-scaling FFAG (Fixed Field Alternating Gradient) facility currently under construction at Daresbury Laboratories. The accelerator will utilise ALICE (Accelerators and Lasers in Combined Experiments) as its injector. EMMA is a compact accelerator of 5.3 m diameter (Figure1). 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. The injected beam will be 10 MeV and will be extracted at 20 MeV, the RF parameters for which are shown in Table 1. Since this is a demonstrator machine, the RF system has been designed with flexibility as a core objective, which includes varying the RF frequency and the rate of acceleration. Initially an acceleration of 2.3 MeV per turn is required with the potential to upgrade to a maximum of 3.4 MeV.

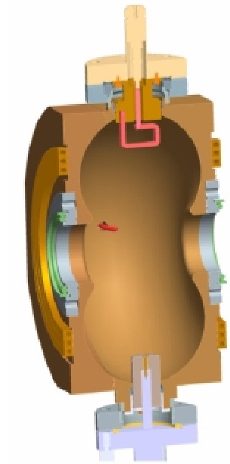
RF SYSTEM

The EMMA RF system consists of 19 identical normal conducting cavities, a waveguide distribution system, a high power RF amplifier [2] and the LLRF system. The current status is that the majority of RF components have been installed on the machine girders (see Figure 2) and beam from ALICE has been transported through the EMMA injection line [3]. The final installation of machine modules including the injection and extraction kickers will take place in June 2010.

Figure 2: EMMA assembly.

RF cavity

The RF accelerating cavity in EMMA [4] has been designed to provide an acceleration of 120 kV per cavity in the initial design for the machine (see Figure 3). There is a possibility to upgrade the acceleration voltage to 180 kV by upgrading the high power RF system. Other components of the RF system have been designed with the upgraded performance in mind. The cavities for EMMA were manufactured by Niowave Inc, USA.



Parameter	Value	
Frequency (GHz)	1.3	
Shunt impedance (MΩ)	2.05	
Q_0	20500	
R/Q	100	
Tuning Range (MHz)	-4.0 to +1.6	
Accelerating Voltage (kV)	120	180
Power to generate voltage (kW)	3.6	8.1
Power including overhead	4.7	10.5

Figure 3: EMMA RF cavity.

RF Distribution

To distribute equal power to 19 RF cavities in such a compact ring design, a novel waveguide distribution system was designed and built by Q-Par Angus Ltd, UK. The system takes power from a single IOT amplifier and using a cascaded network of hybrid power splitters, delivers an appropriate power level to each cavity (see Figure 4). A rejection load and a high power phase shifter is included in each hybrid so that the phase of individual cavities can be optimised and reflected power is appropriately dissipated for each cavity.

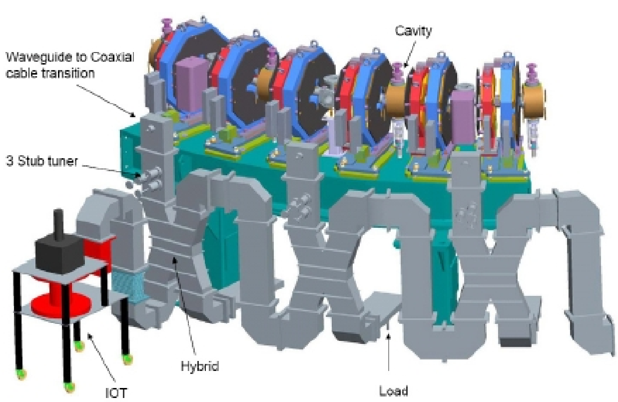


Figure 4: EMMA RF distribution.

Power Amplifier

The power amplifier consists of a CPI IOT (CHK51320W) and a Bruker BLA1500 solid state amplifier (SSA). The SSA has a power output of up to 1 kW pulse mode; this is connected to the CPI IOT to produce up to 90 kW of RF power over the required frequency range of -4MHz to +1.5MHz (f_c = 1.3GHz). The amplifier system comes complete with DC power supplies for the IOT and a local EPICS control system.

Figure 5: CPI 90 kW Power amplifier.

The Low Level RF System

The LLRF system has been designed by Instrumentation Technologies (ITech). It has the task of performing the synchronisation with the ALICE injector, setting initial cavity conditions and then controlling the cavity amplitude and phase to promote stable acceleration in the EMMA machine.

The ITech Libera LLRF system has substantial diagnostic capabilities and is able to calibrate and monitor all nineteen cavity field probe signals, forward and reflected power to each cavity, the IOT power levels and in addition has control of the cavity tuner motors and high power phase shifters installed before each cavity input. The enables the system to apply phase shifts to each cavity independently, producing the required RF phase for successful acceleration around the whole machine. In addition, a frequency control loop on each cavity will be performed using the cavity frequency tuners.

The user interface to the system will be a LINUX based GUI that allows all the diagnostic and controls to be performed remotely. Tests at Daresbury in April 2009 using an IOT, a single Q-Par Angus hybrid splitter and two Niowave cavities showed that the development software was able to control the system at a total peak IOT power of 10 kW (5 kW per cavity) and lock the two cavities together to a level of 0.0082 Degrees and 0.005% amplitude.

Synchronisation

EMMA will be operated over a frequency range of 5.5 MHz (-4MHz to + 1.5 MHz) with respect to the ALICE carrier frequency of 1.3 GHz. This requires a novel solution to the issue of synchronising the two accelerators and is complicated further by timing jitter contributions from the ALICE photo- injector system. This has led to a scheme whereby the Libera LLRF will synchronise itself on every trigger pulse so as to preserve the relationship between the two machines.

Frequency Matched Mode

The Libera LLRF system receives timing signals from the ALICE injector, a pre pulse 200 µs before the beam is triggered and the ALICE 81 MHz and 1.3 GHz RF signals. It then detects the trigger and resets its phase accumulators so that the numerical oscillator inside the FPGA can be synchronised at the output to the correct desired frequency. For frequency matched mode the system needs to be started as follows: -

- A small RF power is fed to all 19 cavities and the response of all forward/reflected and cavity field signals are calibrated.
- Detune all cavities except the reference cavity 1 and close the feedback loop.
- Perform a zero crossing detection using beam diagnostics for this cavity.
- Repeat for each individual cavity and save phase results.
- Load all zero crossing phase offsets and perform diagnostics around the cavity systems.

As the cavities are split unequally around the ring, ten to nine, the cavity frequencies of one arm of the ring are detuned slightly so that the amplitude in each cavity will give the same acceleration voltage to the electron beam. The system is then ready to close the feedback loops around all the cavities and apply a global vector phase shift in response to where the operators would like the cavities to operate.

Frequency Shifted Operation

We expect that EMMA will be operated with a particular frequency for a number of hours or perhaps days. The system can then be restarted at a different frequency to ALICE to enable the physics team to probe machine characteristics. In principle the setup of the system is the same as for the frequency matched mode. However when the Libera LLRF system is loaded with an offset frequency, the system creates a 'virtual reference' that tracks the ALICE 1.3GHz and is retimed after each timing signal. In this manner it is able to maintain the phase relationship between the two machines even though the frequencies are effectively slipping in time. To start the system, the same lists of tasks have to be performed as for the frequency matched mode, zero crossing, detection for each cavity and a plot of phase offsets etc. The Libera system will then realign itself on every triggering event to ensure maximum accuracy is maintained. Once the loop is closed the system is ready to apply an arbitrary global phase offset to all the cavities in the EMMA ring.

The ability of EMMA to run with its RF system off frequency while maintaining synchronisation with the ALICE 1.3 GHz is crucial to the physics program for the machine. The aim of the EMMA experiment is to probe the longitudinal dynamics of a NS-FFAG accelerator, this includes time-of-flight behaviour, the transmission and emittance growth as a function of machine acceleration rate, tune variation and resonance effects.

Installation

Currently the installation of EMMA is in its final stage, most of the hardware is installed leaving only the girders with the injection kicker/septum and extraction system to be surveyed into position. The RF power amplifier, distribution system and the majority of cavities are installed in their final positions. The LLRF has been installed in an air conditioned room some 30 meters outside the accelerator hall (see Figure 6).

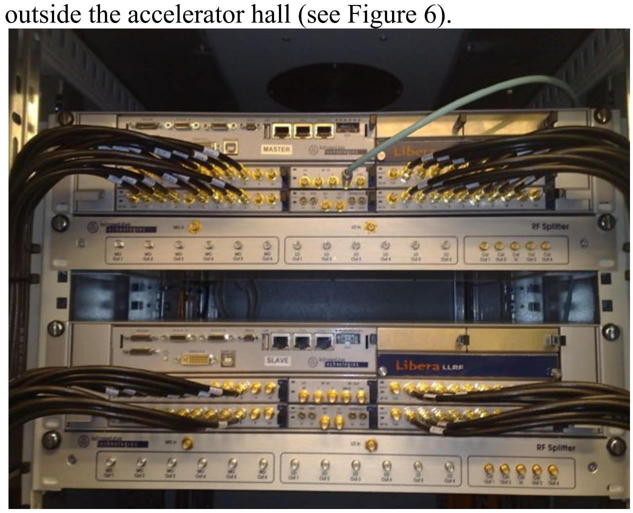


Figure 6: Installed Libera LLRF in EMMA.

Summery

The EMMA machine is in its final installation phase. The RF system is virtually complete and ready to be tested. Beam commissioning is to be started in July 2010 with coasting beams and low power diagnostics. The ITECH Libera LLRF system will provide a flexible, powerful tool which will be fundamental in facilitating the beam physics program on EMMA.

REFERENCES

[1] R. Edgecock et al "EMMA-The World's First NON – Scaling FFAG", EPAC'08, Genoa, Italy, June 2008, THPP004, p. 3380 (2008); http://www.JACoW.org.

[2] A. Wheelhouse et al "Desgin Progress of the RF System for EMMA at Daresbury Laboratory" PAC'09, Vancouver , Canada, June 2009, TU5PF097 (2009); http://www.JACoW.org..

[3] B. Muratori et al "Preparations for EMMA Commissioning", IPAC'10, Kyoto, Japan, May 2010, THPD028, http://www.JACoW.org.