# PREPARATIONS FOR EMMA COMMISSIONING

B. D. Muratori, J. K. Jones, A. Kalinin, A. J. Moss, Y. M. Saveliev, R. J. Smith, S. L. Smith,
S. I. Tzenov, A. Wheelhouse, STFC, Daresbury Laboratory, ASTeC & Cockcroft Institute, UK
D. J. Holder Cockcroft Institute and Liverpool University, UK
G. Cox STFC Daresbury Laboratory, UK
S. Machida, D. Kelliher STFC Rutherford-Appleton Laboratory, UK

*Abstract*

The first results from commissioning EMMA - the Electron Model of Many Applications- are summarised in this paper. EMMA is a 10 to 20 MeV electron ring designed to test our understanding of beam dynamics in a relativistic linear non-scaling fixed field alternating gradient accelerator (FFAG). EMMA will be the world's first non-scaling FFAG and the paper will outline the characteristics of the beam injected in to the accelerator as well as summarising the results of the extensive EMMA systems commissioning. The paper will report on the results of simulations of this commissioning and on the progress made with beam commissioning.

## INTRODUCTION

Non-Scaling FFAGs (NS-FFAGs) were invented at the end of the 1990s [1], principally for the acceleration of muons in a neutrino factory. They are ideal for this purpose as the fixed field allows for rapid acceleration. Further, the non-scaling nature allows the manipulation of the particle orbits to produce a parabolic variation of the orbit length with energy. This gives a much smaller momentum compaction and hence a smaller orbit excursion than for a scaling FFAG, for example. A remarkable feature of these machines is that this small orbit excursion can be achieved with linear magnetic fields. This gives them a large dynamic aperture and the ability to use higher RF frequencies than scaling FFAGs. In addition, it is possible to accelerate relativistic particles over a factor of more than two in momentum without changing the RF frequency (so-called asynchronous or serpentine acceleration), making CW operation possible for muon acceleration. For these reasons, NS-FFAGs have been selected as part of the baseline acceleration system for a neutrino factory. More recently, due to their interesting properties, NS-FFAGs have been studied for other applications, in particular a high power proton driver [2], for proton and carbon cancer therapy [3] and for driving sub-critical nuclear reactors using thorium as a fuel.

The injector for EMMA is an existing machine, Accelerators and Lasers In Combined Experiments (ALICE). ALICE will deliver single bunches of charge 16 to 32 pC and energy 10 to 20 MeV at a rate of 1 to 20 Hz. The EMMA injection line ends with a 70° septum for injection into the EMMA ring itself followed by two kickers to direct the beam onto the correct, energy dependent, trajectory. The injection line is described in [4].

In this paper we briefly describe some of the latest experiments done to characterise the electron bunch before injection into the EMMA ring. We also summarise the latest developments in technical system commissioning, particularly the RF system and the EPICS interface. BPMs are discussed in [5]. Finally, we describe some of the latest ideas and simulations undertaken to compensate for kicker power supply ringing.

## BUNCH CHARACTERISATION EXPERIMENTS

Several experiments to characterise the electron bunch going into the EMMA ring are being developed at present. Firstly, the transverse emittance needs to be determined. This is the subject of [6]. Phase space tomography is available in the EMMA injection and extraction lines and early work on reconstruction techniques is recorded in [7]. Approximate energy measurements have also been done recently in the EMMA injection line shown in Fig. 1. The energy spread at 15 MeV was found to be around 100 keV. This measurement needs to be repeated at different energies and the spread optimised by adjusting the phases in the main ALICE linac. In this way, it is hoped to achieve a apread of less than 30 keV (rms), ideal for operating EMMA.

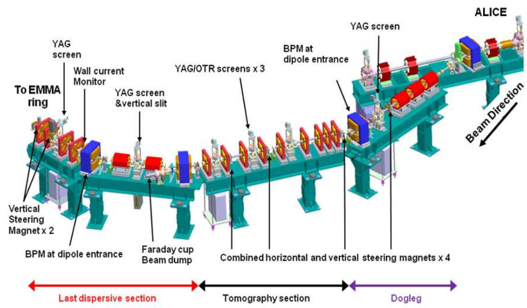


Figure 1: ALICE to EMMA Injection Line.

## SYSTEMS COMMISSIONING

### *EMMA RF*

The RF sub-systems on EMMA are presently being installed and commissioned in readiness for the commencement of commissioning with beam. A more detailed description of the RF system and commissioning progress to date is described in [8]. The RF system is designed to provide a 1.6 ms pulse at 1 to 20 Hz with a frequency between 1.2960 and 1.3015 GHz. The system incorporates 19 identical normal conducting copper cavities in the EMMA ring whose accelerating voltage is provided by a single high power RF amplifier incorporating a 90 kW Inductive Output Tube (IOT) via a unique RF waveguide distribution system, which splits and cascades the RF power clockwise and anti-clockwise around the EMMA ring. The amplitude and phase control of the RF system, along with the synchronization to the 1.3 GHz RF system of ALICE is provided a Low Level RF (LLRF) system.

The high power RF amplifier system has been supplied and installed by CPI. Acceptance tests have been successfully performed showing that the system is capable of delivering 90 kW across the full frequency range. Additionally low power acceptance tests have been performed on the RF waveguide distribution system developed by Q-par Angus, which is now presently under construction. Finally the LLRF system has been delivered and installed, with commissioning tests planned for June 2010.

### *EPICS INTERFACE*

Development of high-level software is one of the keys to successful commissioning. All the hardware and diagnostics are connected to EPICS and virtually no signals are available otherwise. For EMMA, a virtual accelerator was constructed in parallel to the real machine. A sequence of algorithms for the high-level software are being tested using the virtual accelerator. Fig. 2 shows an example which reads BPM signals and calculates cell tune. The same software will be used for the real machine just by changing the prefix of Process Variables (PVs). More details of the

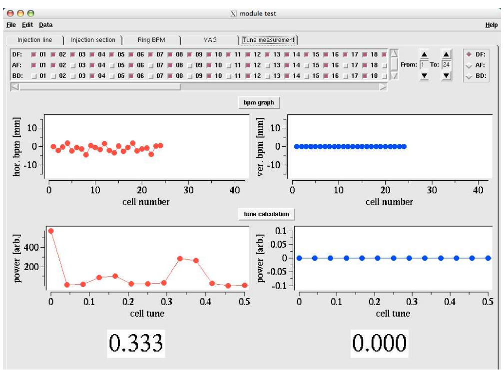


Figure 2: Cell tune measurement panel. In this example, BPM signals of the first 24 cells are used to calculate cell tune.

implementation of high level software together with the development of an online model for EMMA can be found in [9].

## KICKER RINGING SIMULATIONS

The basic elements of the injection system adopted in the EMMA ring are a septum magnet and two kicker magnets, located in two successive long straight sections immediately after the long straight section, where the septum is inserted. The extraction system is simply a mirror image of the injection one. Since during acceleration the beam passes many times through the kicker, it is desirable that there is no kicker field acting on the beam during the successive passes. The initial kicker design assumed a scheme, where the magnetic field vanishes after one turn, corresponding to a time period of approximately 55 nanoseconds.

In an ideal case, where the magnetic field of the two kickers drops to one percent or less of the peak field within 55 nanoseconds, an injection simulation is performed directly by tracing backwards the injection orbit of a reference particle from a point on the reference trajectory after the second kicker to the septum magnet. This is one-turn injection.

A natural question that arises is whether a multi-turn injection in a NS-FFAG accelerator is possible. An intuitively clear way to realize such a scheme is to abandon the principle that the beam should be placed on a reference trajectory after the first pass through both kickers. It turns out that at the first pass bunches could be injected onto an orbit sufficiently close to the equilibrium one such that the residual kicker magnetic field does the rest of the job in placing the bunches on the true equilibrium orbit during the second turn. The only restriction of this scheme is the requirement that the trajectory excursion should remain well inside the physical aperture of the machine.

The main reason for adopting a multi-turn injection scheme in EMMA is the difficulty in building a kicker power supply which produces a ringing field of less than one percent of the peak magnetic field after the single pass orbit time of 55 nanoseconds. The measured field decays exponentially but unfortunately is still about 10% of the peak value after the second pass of the bunch through the kicker, as shown in Fig. 3. The modelling of the two-

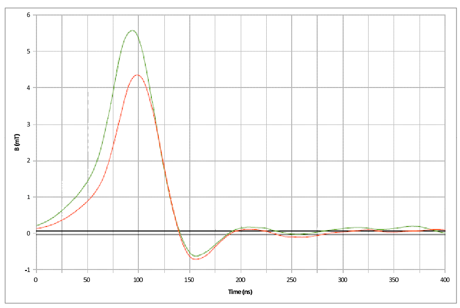

Figure 3: Time patterns of the kicker magnetic field, red curve = B field at 20 kV, green curve = B field at 26 kV, black lines = ± 1% (26 kV).

turn injection involves two passes of the beam through the kicker fields. During the first pass they are set to their peak value and are fired at the correct time, while during the second pass their amplitude is reduced to 10% of their peak and the polarity is reversed.

The results of a simulation of the effect of a 10% ringing field at 10 MeV with single turn injection is shown in Fig. 4. This is the worst case scenario and things get progressively better as we increase the energy. This can be seen if we look at the minimum and the maximum deviations of the trajectory with respect to the EMMA polygon centre line as a function of energy, shown in Figs. 5 and 6, respectively. An obvious extension of this work is a

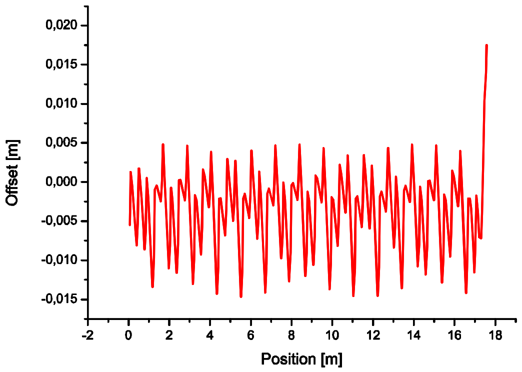


Figure 4: Orbit at 10 MeV with 10% kicker ringing.

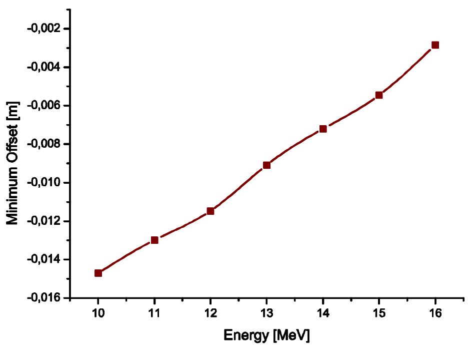


Figure 5: Minimum deviation of the trajectory versus energy due to kicker field ringing of 10%.

detailed examination of how the beam is placed onto the closed, energy dependent, orbit. This is the subject of a further paper at this conference [10] and the dynamics has been presented in [11].

## OUTLOOK

Current plans include the start four-sector commissioning by mid-June followed by full machine commissioning by the start of August. Four sector commissioning

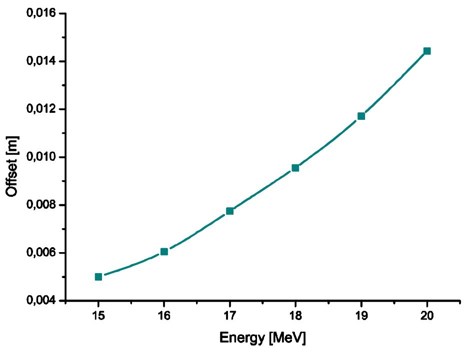


Figure 6: Maximum deviation of the trajectory versus energy due to kicker field ringing of 10%.

means the commissioning of a portion (just over half) of the EMMA ring. This will provide insight into full commissioning and, in particular, gantry design [3].

## REFERENCES


[1] C. Johnstone et al, Fixed Field Circular Accelerator Designs, PAC99, New York, March 1999, p. 3068.

[2] G.H. Rees, Proton Acceleration - ADS - RIA: 10-MWNS-NL FFAG SNS, FFAG07, Grenoble, April 2007.

[3] E. Keil et al, Hadron Cancer Therapy Complex Employing Non-scaling FFAG Accelerator and Fixed Field Gantry Design, EPAC06, Edinburgh, July 2006.

[4] R. D'Arcy et al. (2010) 'Modelling of the EMMA NS-FFAG Injection Line using GPT'. These Proceedings (MOPEC046).

[5] A. Kalinin et al. (2010) 'Diagnostic System Commissioning of the EMMA NS-FFAG Facility at Daresbury Laboratory'. These Proceedings (MOPE068).

[6] J. M. Garland et al. (2010) 'Characterisation and Optimisation of the ALICE Accelerator as an Injector for the EMMA NS-FFAG'. These Proceedings (THPD030).

[7] M. G. Ibison et al. (2010) 'Development of Tomographic Reconstruction Methods for Studies of Transverse Phase Space in the EMMA FFAG Injection Line'. These proceedings (THPD031).

[8] A. Wheelhouse et al. (2010) 'Commissioning of the EMMA RF System at Daresbury Laboratory'. These proceedings (THPEB056).

[9] Y. Giboudot et al. (2010) 'Recent Developments On The EMMA On-line Commissioning Software'. These Proceedings (THPD024).

[10] S. I. Tzenov et al. (2010) 'Setting the Beam onto the Reference Orbit in Non Scaling FFAG Accelerators'. These proceedings (THPD029).

[11] J. K. Jones, B. D. Muratori, S. L. Smith and S. I. Tzenov 2010, 'Dynamics of Particles in Non-Scaling FFAG Accelerators'. *Progress in Physics, Vol. 1 (2010) 72-82*.