EMMA COMMISSIONING*

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Abstract

EMMA (Electron Machine with Many Applications) is a prototype non-scaling electron FFAG to be hosted at Daresbury Laboratory. NS-FFAGs related to EMMA have an unprecedented potential for medical accelerators for carbon and proton hadron therapy. It also represents a possible active element for an ADSR (Accelerator Driven Sub-critical Reactor). This paper summarises the commissioning plans for this machine together with the major steps and experiments involved along the way. A description of how the 10 to 20 MeV beam is achieved within ALICE is also given, as well as extraction from the EMMA ring to the diagnostics line and then dump.

INTRODUCTION

Commissioning an accelerator proceeds through a number of clearly defined stages, starting with the hardware and followed by commissioning with beam; although progress is usually dependent on the previous step being completed some iteration is also usually required. This paper concentrates on beam commissioning of EMMA [1], assuming all hardware is ready. Thus the key activities will be operating the control system to manipulate and control the electron beam and particularly setting up the diagnostics and its associated data acquisition software (DAQ), controls and hardware. Initially, it will be necessary to ensure we can transport the beam in the machine to whichever location we want. Next, it is vital that we can measure all the bunch properties we desire so as to have as full a characterisation as possible of the six dimensional phase space of the bunch. This goes hand-in-hand with ensuring that the machine itself is set up to be as close as possible to its designed operational parameters, such as making sure dispersion free straights are as described.

MEASUREMENT DIAGNOSTICS

Table 1 lists the beam measurements and associated diagnostics that will be available in EMMA. In addition to the diagnostics themselves, EMMA commissioning will need the support of a comprehensive online model. This will include the most up-to-date ALICE model extended to include EMMA injection plus a model of the EMMA ring. The EMMA extraction line model may also be based on the ALICE model.

Commissioning of diagnostic controls data acquisition software before EMMA commissioning commences is similarly important. Some of this will already be available from ALICE experience (in particular, we expect the ALICE to EMMA injection line and most of the EMMA extraction line to use very similar software to ALICE). However, there may be some significantly different requirements which will entail modification and testing of existing ALICE software, which could be done on ALICE in advance.

Table 1: Measurements and Diagnostics

Measure-ment	Device	Number	Required resolution
Beam position	4 button BPM	2/plane/cell in ring 4 in injection 3 in extraction	50 µm
Beam profile	OTR / YAG screens	2 in ring, 6 in injection & extraction line	20-30 µm pixel size
Beam profile	Wire scanners	2 in ring	10 µm
Beam current	RWM	1 RWM 1 scope	2%
Phase	RWM	As above	10°
Trans-mission	RWM	As above	2%
Bunch charge	Faraday cup	1 at injection, 1 at extraction	2%
Beam loss	Beam loss monitor	4 in ring	2%
Momentum	BPMs and TOF from RWMs	Already included elsewhere	100 keV
Emittance	Tomo-graphy diagnostic	Injection & extraction lines	10%
Extracted momentum	Spectro-meter	1 (diagnostics line)	1%
Longitudi-nal profile	TDC and screen	1 (diagnostics line)	20 keV and 5°
Slice emittance	TDC and screen	1 (diagnostics line)	Slice about 6, 0.2 mm on screen
Slice energy spread	TDC and screen	1 (diagnostics line)	5 keV and 5°

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BEAM PARAMETERS

EMMA operation requires different beam parameters to the usual ALICE operation ones, in particular:

- Bunch length: ~ 10 ps rms in order to decrease space charge effects and for painting the longitudinal phase space;
- Energy spread: < 100 keV in order to have a better defined beam for painting;
- Bunch charge: 16 – 32 pC in order to reduce collective effects (e.g space charge);
- Normalised transverse emittance: 5 - 10 µm in order to decrease space charge effects but still have a well defined beam for painting;
- Beam energy: 10 to 20 MeV with the ability to be changed several times a day.

EMMA INJECTION LINE SET UP

The design of the EMMA injection and extraction lines are described here [2]. It is convenient to subdivide the EMMA injection line into three sections in order to show the function of each part; dogleg, tomography and last dispersive section. This is shown in Fig. 1. The first task here is to set zero dispersion in the dogleg section, before matching the beam into the tomography section. The intention is to undertake a full characterisation of the beam at this point, before attempting injection into EMMA. The last dispersive section before entrance into the EMMA ring contains an OTR/YAG screen and a vertical slit for energy and energy spread measurements. There are horizontal and vertical steerers in the line for positioning and centring the beam at the entrance of EMMA.

INJECTION INTO EMMA RING

Once everything has been set for injection into the EMMA ring, a low charge, small diameter beam can be threaded into the machine, probably at a middle-range energy (and without acceleration). The beam will be transported around in progressive steps:

- Set an initial charge at 1 pC or whatever the lowest detectable by the BPMs is;
- Initially aim for a half turn of EMMA followed by extraction, threading beam round without acceleration from BPM to BPM;
- Measure beam properties in the extraction line;
- Repeat the previous step, this time with the RF system on but no acceleration, in order to test synchronisation. This will operation of the EMMA cavities at zero crossing.

Following this half turn, one and a half and then several (more than ten) turns will be attempted. Once a beam has been successfully injected, we have to establish the orbit for one of the eight proposed EMMA lattices. For this we need to look at the BPMs and adjust the initial beam position (x, x', y, y') as well as the quadrupole currents and positions. This is not straightforward because one cannot look for symmetry in the BPM readings as one does in a circular machine, because these are not symmetrically placed in the cells. Also, if we are accelerating, the beam changes its 'orbit' after every cavity and there is no real symmetry at all. However, the geometry is known and it is possible to use existing EMMA models to predict what the BPM readings should be. Furthermore, there are four variables, the QF and QD strengths and horizontal positions, and four constraints.

The four constraints are the horizontal and vertical tunes, the horizontal position and the energy where the Time Of Flight (TOF) is minimal. This may require operation at a higher than minimum charge to get the best signal-to-noise ratio from the BPMs. Once we are happy with the set-up of the EMMA ring, we can proceed to higher charges. Only when we are confident that we have a reasonable understanding of the closed orbits in the ring will acceleration be attempted. It will be necessary to repeat the tune and TOF measurements at several energies to fully characterise the ring.

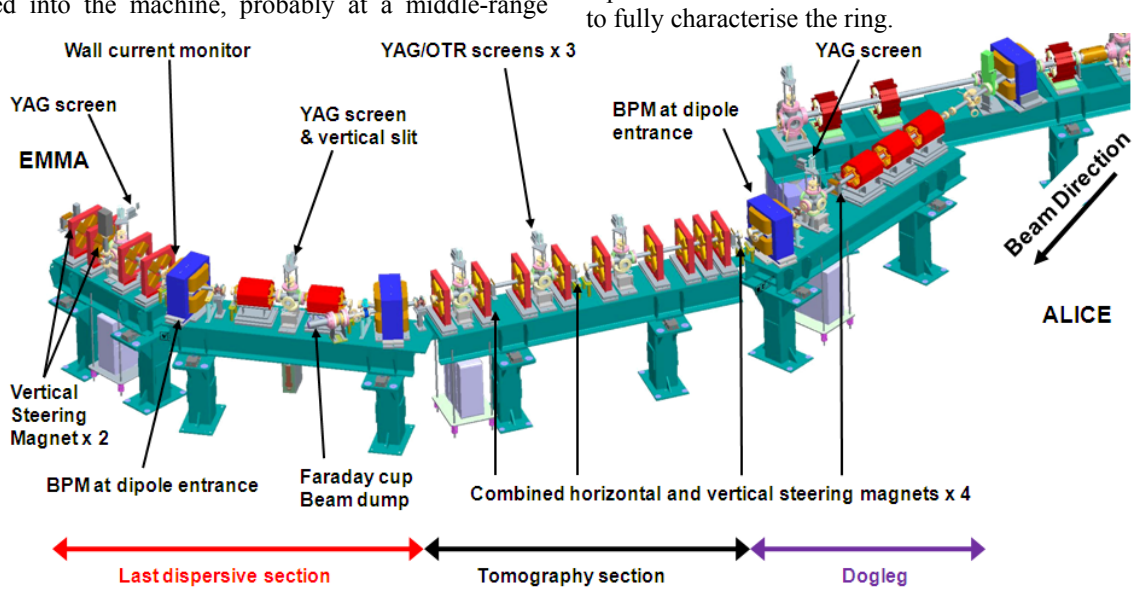

Figure 1: Layout of EMMA injection line.

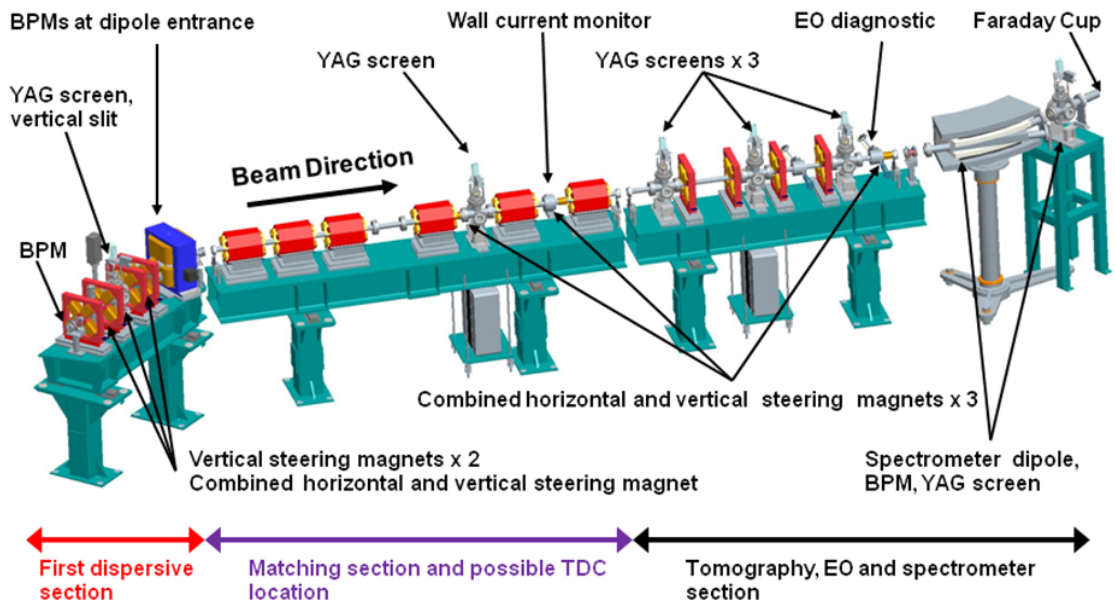

Figure 2: Layout section of EMMA extraction line.

EXTRACTION LINE SET UP

Extraction is much more difficult than injection because, in the worst case scenario and when we accelerate, we do not have a precise knowledge of the extraction energy or where the beam will be. Chromaticity will spread the beam out in phase space so it is likely that we can only extract part of the beam.

Figure 2 shows the EMMA extraction line subdivided into three: the first dispersive section, a matching section (with possible Transverse Deflecting Cavity (TDC) location); and tomography, Electro-Optic (EO) diagnostic and spectrometer section. The main purpose of the first dispersive section is to allow for initial energy measurements and to zero the dispersion coming from the EMMA ring ready for the diagnostic straight. The matching section is used to match the beam to the tomography section with the possible inclusion of a TDC to measure longitudinal profile and slice emittance and energy spread. The EO diagnostic is for measurements of bunch length and the spectrometer for energy measurement.

FULL CHARACTERISATION

Once the initial commissioning of the EMMA complex has been completed, it will be necessary to systematically characterise the behaviour of the ring and progressively optimise the set up to approach the design configuration. This process will consist of the following steps:

1. Choose the configuration;
2. Choose the energy;
3. Set up injector and injection line;
4. Achieve circulating beam without RF;
5. Capture beam in stationary buckets with RF;
6. Measure time of flight (from RF frequency), tunes, orbits, beta functions, dispersion, etc.;
7. Set up extraction at this energy after a specified number of turns;
8. Repeat 2 to 7;
9. Use information from several energies to determine any changes to quadrupole positions and excitations in order to get closer to design configuration;
10. Return to 2;
11. Accelerate outside buckets;
12. Return to 1.

Commissioning EMMA will present many challenges, and a successful outcome will prove the viability of non-scaling FFAGs for many future accelerator applications.

REFERENCES

[1] S.L. Smith et al., “EMMA, the World's First Non-Scaling FFAG Accelerator”, these proceedings.
[2] B.D. Muratori, S.L. Smith, S.I. Tzenov, C. Johnstone, “Injection and Extraction for the EMMA ns-FFAG”, EPAC’08, Genoa, July 2008.