THE EMMA ACCELERATOR, A DIAGNOSTIC SYSTEMS OVERVIEW*

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Abstract

The 'EMMA' Non-Scaling Fixed Field Alternating Gradient (ns-FFAG) international project is currently being commissioned at Daresbury Laboratory, UK. This accelerator has been equipped with a number of diagnostic systems to facilitate this. These systems include a novel time-domain-multiplexing BPM system, moveable screen systems, a time-of-flight instrument, Faraday cups, and injection/extraction tomography sections to analyse the single bunch beams. An upgrade still to implement includes the installation of wall current monitors. This paper gives an overview of these systems and shows some data and results from the diagnostics that have contributed to the successful demonstration of a serpentine acceleration by this novel accelerator. [1]

INTRODUCTION

The Electron Machine of Many Applications (EMMA) [2], is now undergoing commissioning and experimental investigation. EMMA is a proof-of-principle prototype for a ns-FFAG type of particle accelerator, designed by an international team of scientists, including a number of the UK's predominant universities and institutes. EMMA is funded by the Research Councils UK (RCUK) Basic Technology programme.

EMMA's novel, compact design consisting solely of remotely moveable focussing and de-focussing DC quadrupole magnets around a small (~50 mm) diameter vacuum vessel, presented a number of challenges for diagnostic systems.

EMMA LAYOUT

Due to the small size and tightly packed infrastructure consisting of 84 quadrupole magnets, and 19 RF accelerating cavities and injection/extraction Septa, the space available for diagnostics is severely restricted. The challenge therefore was to diagnose, understand and direct issues to be faced in the design of future FFAGs. For a typical bunch charge 30pC, Table 1 shows a list of the basic parameters required to be measured at EMMA, and the diagnostic systems utilised. These systems are discussed here.

Table 1: EMMA Diagnostic implementation

Measurement	Device	Number	Required resolution
Beam position RING	4 button BPM	82	50 um
Beam position INJECTION	4 button BPM	7	50 um
Beam position EXTRACTION	4 button BPM	5	50 um
Beam profile RING	Screens	2	100 um pixel size
Beam profile INJECTION	Screens	5	100 um pixel size
Beam profile EXTRACTION	Screens	6	100um pixel size
Beam current ALL	Wall Current Monitor (WCM)	3	5%
Transmission	WCM	As Above	5%
Transmission	Faraday Cup	2	5%
Momentum RING	BPMs and WCMs		100 keV
Momentum EXTRACTION	Spectrometer	1	1%
Emittance INJ/DIAG	Screens	3	10%
Longitudinal profile EXTRACTION	Electro Optic station	1	20 keV and 5 degrees

BEAM POSITION MONITORING

By far the most complex and comprehensive diagnostic system installed, is that of the Beam Position Monitor (BPM) system. [3] Although the same BPMs are used in the Injection Line (IL), Extraction Line (EL) and in the EMMA Ring, it was the ring that provided the most difficulty due to the tight packing of the many components required.

BPM Pickups

Circular orthogonal type pickups are used almost entirely throughout EMMA, with the exception of four rectangle 'rotated' type pickups placed immediately after each Septum. All pickups utilise 20 mm diameter buttons welded into dedicated inserts that match the internal

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diameter of the vacuum pipe. A typical view of the pickup design can be seen in Fig. 1.

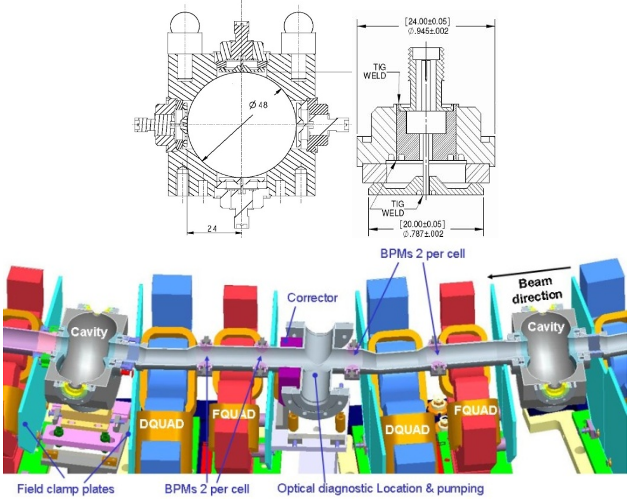

Figure 1: A typical EMMA BPM pickup and Installation.

Electronic Detector and Data Acquisition

The detector and data acquisition BPM electronics is an in-house design, in which the BPMs are organised in two stages. The stage one includes locally mounted Front-Ends (4, 82, 3 of Front-Ends for each plane in IL, Ring and EL respectively). Each Front-End converts and multiplexes two signals from a pair of opposite button pickups and feeds this doublet into a single cable that transmits it to the stage two. The separation in a doublet is 13.8ns (1/4 of the EMMA revolution period). A pair of doublets are shown in Fig. 2.

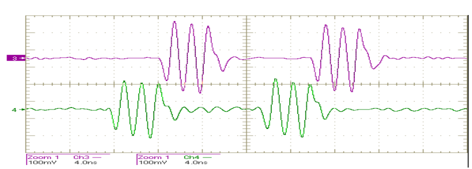

Figure 2: Horizontal and vertical Front-End output doublets.

The stage two consists of two-plane VME cards that are located some 50 m away in an EMMA instrumentation room. Each card amplifies, detects and measures the Front-End signals and clocks them into a local on-board memory that can hold up to 4000 individual turns. Turn/time stamping is achieved by regeneration of clocking pulses from the input beam signal itself. This locally stored data is then read out between successive injections (5 Hz rate), via an EPICS control system.

The EMMA BPM system is interfaced to the EPICS control system via seven VME crates. Each VME crate has a MVME5500 processor running a VxWorks real-time operating system, and can serve up to twenty BPM cards. VME interrupts are generated by the BPM cards independently and each card is serviced by the processor as required.

Voltages captured from the BPMs are stored in EPICS waveform records. A data archival and retrieval system, that eventually take the voltages from the EPICS database and collate and store them in an SQL database for post-processing, is also provided.

The post-processing starts with calculation of true pickup voltages how it is described in [3]. After calculation of a raw bunch offset, a polynomial mapping is done to exclude pickup non-linearity. Maiden EPICS BPM measurement of EMMA orbit is given in Fig. 3. Black dots are measurements by each BPM for twenty subsequent injections, a red curve is the average. A blue curve is obtained from 'direct' measurements of BPM Front-End signals by a digital scope with averaging and off-line post-processing. It is seen that agreement is quite well but some BPMs are not in working order and their electronics, connection, etc., need assessment.

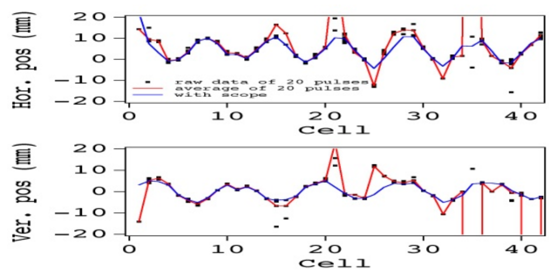

Figure 3: Maiden EPICS BPM orbit measurement.

BPM resolution was measured on a BPM connected to an ALICE injector rectangle pickup. For a number of bunches in an ALICE train, the resolution was calculated as a std of a bunch-by-bunch 'quadrupole' combination of the BPM voltages. [4] For bunch charge 30pC the resolution was measured as about 30µm.

BEAM IMAGING

Actuated imaging systems employing YAG-Ce crystal screens are used throughout EMMA. Injection and extraction lines use compressed-air-operated vertically mounted 'in/out' systems that are imaged by a multiplexed TV camera system.

EMMA Ring Screens

The screens within the EMMA ring, employ horizontally driven stepper motors, driven in from the outside (lower energy side) of EMMA, with cameras mounted above. These novel screens exploit the mechanical rigidity of the YAG-Ce material and provide a dual function, in that the crystal is mounted in a three sided frame, giving an edgeless design. In this way, the screen can be driven and an individual turn position found or imaged, as the beam traverses across the chamber during acceleration. In this way the screen system operates as a single bunch scanner.

BEAM TOMOGRAPHY

An EMMA injection line, shown in Fig. 4, consists of a dogleg to extract the beam from the ALICE injector, a tomography section and a short dispersive section with two dipoles, prior to the injection septum. After the dogleg, the beam is matched into a tomography diagnostic whose purpose is to provide a quick and accurate measurement of Twiss parameters, emittance and transverse beam profile. To study the physics of a ns-FFAG, it is important to have the energy spread of the beam at the start of the injection line minimised. By carefully choosing the phases of the ALICE linac cavities, it was possible to achieve an energy spread less than 0.05% (5keV at 15MeV).

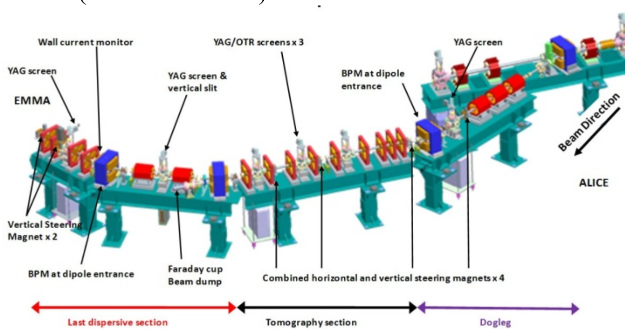

Figure 4: EMMA Injection Line Tomography Section.

The injection and extraction tomography sections are identical to that in design, thus allowing the effects EMMA has had on the beam to be determined. In the extraction straight following the dogleg, are quadrupole magnets used to match the beam directly into the tomography section. Following the tomography section, there is a spectrometer dipole and screen to measure the energy of the beam. Between the tomography section and the spectrometer dipole, there is foreseen an Electro Optic diagnostics to measure the bunch length and longitudinal profile. After the spectrometer dipole is a Faraday cup for bunch charge measurements.

FARADAY CUP MONITORS

The Faraday cups are copper cone-shaped collectors that are identical to those used on the ALICE injector. A typical system is shown in Fig. 5.

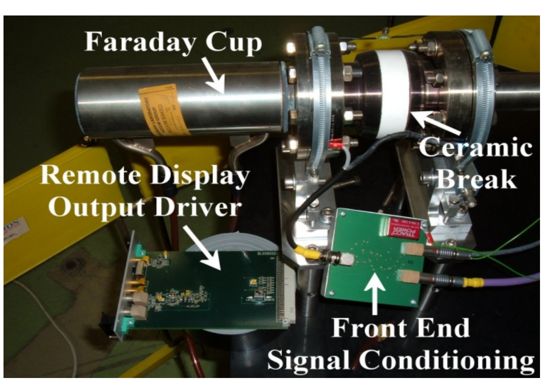

Figure 5: Faraday Cup and its Front-End together with an Output Driver.

The cups are instrumented by a bespoke electronic design employing two stages. A local signal conditioning stage takes the electrical pulse from the cup and then transmits it to the remotely located display driver electronics, which when viewed on an oscilloscope provides a direct conversion value to the actual charge collected.

WALL CURRENT MONITORS

A broad-band 2Ohm resistive WCM has been under development with international collaborators. EMMA has reserved places for three identical devices still to be installed, one each for the injection/extraction straights and the ring itself. An 'in-flange' design (shown in Fig. 6 right), is used in order to more realistically re-produce the bench test performance in the installed location. The device and bench test results for the four units are shown in Fig. 6.

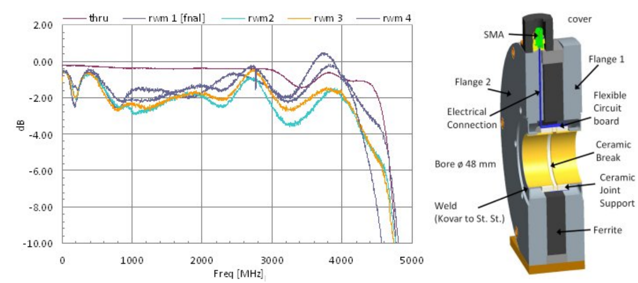

Figure 6: WCM Design and test results of four Monitors.

SUMMARY

The screen systems are fully commissioned and have further underpinned the successful closed orbit operation in everyday use. The injection line tomography section is in regular use to check the injected beam energy spread. The injection and extraction line Faraday cups provide monitoring of overall losses.

On the way of commissioning of the BPM system, it was discovered that an external noise from EMMA kickers and from RF system as well is unacceptably high. A remedial shielding both of the kickers and BPM Front-Ends was required to be done to mitigate this. In this time, for trajectory, orbit, and tune measurements, the Front-End signals were directly digitized by a broad-band oscilloscope and off-line processed. EPICS BPMs have shown encouraging results but, in addition to a routine rectifying of the BPM failures, it is necessary to modify the VME processor firmware and optimise the BPM software to fully exploit the full capability of this system.

REFERENCES

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