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INSTALLATION, USE AND FOLLOW-UP OF AN EMITTANCE-METER AT THE ARRONAX CYCLOTRON 70XP

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Abstract

The 70 MeV cyclotron group of the Arronax GIP (Interest Public Group), France, foresees to increase its beam intensity on target. For this, several beam studies are being performed in the various sections of the accelerator including the injection. Thus, an Allison-type emittance-meter has been installed in this section above the cyclotron and downstream a quadrupole triplet. Installation and the first results of a campaign of measurements are presented including high intensity runs, up to 1 mA for 40 keV H- ions. The emittance-meter is expected to be used with several accelerators throughout the world. Therefore, a strategy on the follow-up of the activation of sample materials used in the equipment is being established and is described in the paper.

INTRODUCTION

The C70XP cyclotron of the Arronax GIP (Public Interest Group) has a wide range of intensity capacities [1] to provide concurrently multi-ions to several beamlines. A program of developments is currently being carried out and concentrates on the injection of the accelerator. It focuses on a chopper system which ejects bunches to form trains of bunches sent to the users. This system allows to deliver high intensity beam for experiments requiring time resolved studies, such as flash proton therapy [2]. The program also encompasses investigations of the transverse dimensions of the beams and potential future permanent diagnostics or constrains (collimators and scrapers) in the low energy section. This program explores the possibility to increase the intensity for example for radioisotope production. Evolution of the beam emittance with respect to the source and injection magnets settings is decisive.

The IPHC has optimised an emittance-meter (EM) based on the Allison principle. The device is designed to withstand high intensity beam at low energy and to be compatible with several major ion accelerators that are being used or built at the present time. Its compactness and ease of use, made it a prime tool for the envisaged investigations during campaign measurements on the C70XP.

PROGRAM OF THE C70XP CYCLOTRON

Runs with beam extraction at high intensity and high energy occur on a regular basis at Arronax. Protons, generated from accelerated H^-, are used over several days at 70 MeV at intensity of 150 µA for ^{82}Sr and up to 220 µA for experimental tests. 16 MeV D^+ up to 85 µA and He^{2+} at 67 MeV up to 20 µA are also extracted, respectively for ^{64}Cu and ^{211}At production over several hours. Particularly with protons, runs can accumulate an ambient global measured dose above several thousands of mSv in the vault. This level precludes the use of sensitive electronics in the cyclotron vault while long duration runs are done: Electronics in this environment can stop working correctly and materials can be activated by the neutron ambiance.

SOURCE AND INJECTION SECTION

The source benches are located above the cyclotron and comprises a multicusp H^-/D^- and a Pantechnik He^{2+}/HH^+ ECR Supernanogan source. The high voltage is around 40kV for the H^- and 20 kV for the other ions, transporting the beam through several magnets to the buncher. Downstream, a chamber, which usually accommodates a faraday cup, has been modified to receive the EM as shown in Fig. 1.

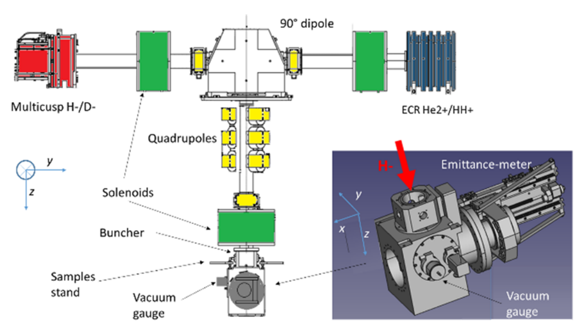

Figure 1: The emittance-meter in the injection beamline above the cyclotron.

EMITTANCE-METER

The EM is a new high resolution 2D phase space scanner device. It is based on the Allison principle and developments performed at IPHC in the 2000s, see Fig. 2. Used initially to assess beam quality for low energy beam transport lines of linac accelerators (SPIRAL 2, FAIR, MYRRHA [3]), the aim is to develop applications for the injection channel of cyclotrons. Strategy was to limit innovation to reasonable level. There are many examples of in-

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novative products with insufficient reliability that subsequently had to be abandoned and industrial equipment is no exception.

The new unit has been constructed between 2018 and 2020 in collaboration with labs of IN2P3 and JINR. The scanner is composed of two aligned slits separated by an electrostatic deflector, and a Faraday cup at the exit in order to collect the charges of selected beamlet. It is able to measure beam of 1 µA to 3 mA DC total current intensity. The dynamic range should be extended to 5 orders of magnitude in the near future (10 nA-3 mA). Beam emittance is calculated from position of slits i.e. stepping motor readout and incidence angle of beamlet. The latter is obtained from HV supply readout as deflection angle is proportional to applied voltage in the first order. The other design parameters are defined in reference [4]. Fringe-fields, space charge effect, off-axis ions influence (non-paraxial trajectories) and other artefacts are generally supposed to be negligible but are generating errors in the order of a few percent. Those side effects are currently being investigated and should lead to a new generation of scanner in the coming years.

Figure 2: EM installed on injection channel of linac accelerator. Double-unit configuration used for 2+2 D scan installed in same focusing plane. The actuators and mechanical structures in blue, bellows and flanges with feedthroughs.

INSTALLATION AND INTEGRATION

A generic industrial 700W CW5000 chiller, with a closed-loop circuit for de-ionised water, was connected via VHN4/SVHC4 couplers to the input/output of the EM and located 3 m away. The temperature was thus regulated to 23°C. A dedicated clamping ISO-K flange was built to receive, align and adapt the position of the device perpendicular to the vertical beam pipe. An additional flange was built for a penning gauge such that vacuum pressure could be measured at the location of the EM. Once in position, the slit of the EM was centered according to a vertical laser mark, simulating the centroid of the beam.

The current amplifier card (FEMTO DHPCA-100 card) remained in the cyclotron vault, while the DAQ and controller system were installed in a dedicated room, 20 m away, which was checked not to affect the signals.

FOLLOW-UP OF MATERIAL ACTIVATION

Prior to the usage of the EM, a measurements campaign of sample materials representative of the ones used for the device was carried out. This preliminary campaign was performed with high intensity runs. The samples were copper and 316 L stainless steel cylinders (h×ϕ=5×20 mm), a tungsten block (L×l×h=27×7×2 mm) and de-ionised water. They were installed on a stand close to the injection (Fig. 1).

The sample resided 137 days in the vault. Gamma spectrometry analyses using HPGe detector (Ortec Micro-Detective) and Monte-Carlo detection efficiency transfer code [5] revealed non-negligible samples activation.

The day after the samples were taken out of the cyclotron vault, the stainless steel, copper and tungsten samples contained a specific activity, at the same time stamp, of 43.28 Bq/g, 4.91 Bq/g and 25.16 Bq/g, respectively. 91.1% of the stainless steel sample activity being due to ^{51}Cr (T1/2=27.7 d), while copper sample activity being mainly due to ^{64}Cu (T1/2=12.7 h). Finally, ^{187}W (T1/2 = 24 h) represents 96.2% of the tungsten sample activity.

As a consequence, the EM was chosen to be systematically removed from the cyclotron vault after each period of campaign in order to limit its activation. This procedure ensured that the material remained below the exemption values for later transport to other laboratories.

No significant activation was measured on the slit and cup of the EM due to direct beam irradiation. Finally, the complex external geometry of the EM does not allow an easy quantification of its potential future activation. Another batch of standardized samples was placed in the immediate vicinity during its use in the cyclotron vault and thus ensures the follow-up of its activation. This latter defines a proposed protocol for future follow-up of the EM, being accompanied by the samples.

PRELIMINARY MEASUREMENTS

The slit can be moved for a scan over more than 140 mm and the applicable voltage between the plates of deflector of the EM is, at 10^{-5} mbar, up to 1400 V i.e. up to 100 mrad. At each step (0.2 mm, 20 V) of the scan, i.e. at a position of the slit and deflector voltage, the deposited current is measured by the amplifier card, converted and recorded in the DAQ. The input of the card was connected to 1 MΩ impedance, while the output was connected to a 50 Ω charge.

Typical Scans

The main campaign of measurements spanned over seven days. For this, the H^- source is switched on/off at the beginning and end of the day, for reproduction studies. A typical set of parameters for the source and injection magnets is used to start up measurements with the reference set initially optimised for runs at 150 µA at the end of the beamline. Particularly the arc current of the multicusp source is fixed at 2 A (V_arc=118.1 V). Measurement is shown in Fig. 3 (left), indicating the distribution of the

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reading voltage, proportional to the intensity of the H-beam at each step of the position (x) vs angle (x') of EM.

Emittance Calculation

In order to get an offline overall estimation of the emittance, 2D Gaussian fits of the (x,x') distributions are applied. The background signal is also fitted with a 2D (x,x') plane and a pixel matrix cleaning is used. This technique helps to mitigate results dependent of the definition of the measurement window, specifically when the centroids in x and x' moves and tail of the distribution is cut. This calculation fit is still under scrutiny and is considered for the comparison studies here.

Source Arc Current Impact

After a warmup time, to stabilise the beam intensity, the arc current is set and a measurement of the (x,x') distribution is performed. This is part of a global systematics study and so no further optimisation is performed. An example is given in Fig. 3 (right), with the arc current at 5 A (equivalent to 1.1 mA at the position of the EM), the distribution shows several concentration spots. The distribution is fitted with a single ellipse giving an overall 1-σ geometric emittance of 19.7 pi.mm.mrad.

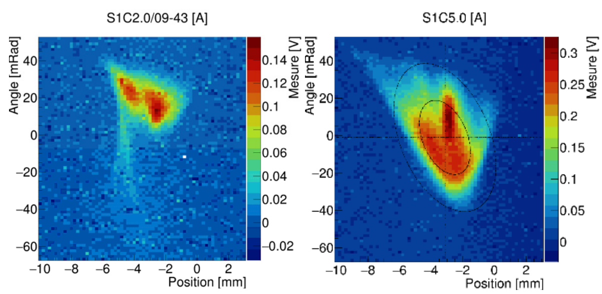

Figure 3: (x,x') Distribution of the H^- beam. On the left, the source current (S1C) is fixed at 2 A. It is the start-up reference beam. On the right, one of the measurements for the arc current ramped up to S1C=5 A. Also, 1 and 2-σ ellipses are drawn, with the centroid (cross).

As an initial analysis of the impact of a simple knob, emittances are drawn according to the arc current in Fig. 4 for several start-ups. The 1-σ emittance ranges from 5 to 30 pi.mm.mrad as the source arc current increases and decreases above 6 A. This decrease is accompanied by a lower intensity transmission. Other parameters of the source, such as the electron suppressor, the ion puller and the high voltage have been investigated and also the impact of the quadrupoles settings. These are still being analysed.

Also because the EM is a few cm above the cyclotron main yoke, the impact of the settings of the Main Coil (MC) was examined. For a few Amps of modification (within the standard operational changes), no major impact was observed on the emittance. Though, the switch-off of the MC modified drastically the emittance, necessitating a complete optimisation of the injection beamline.

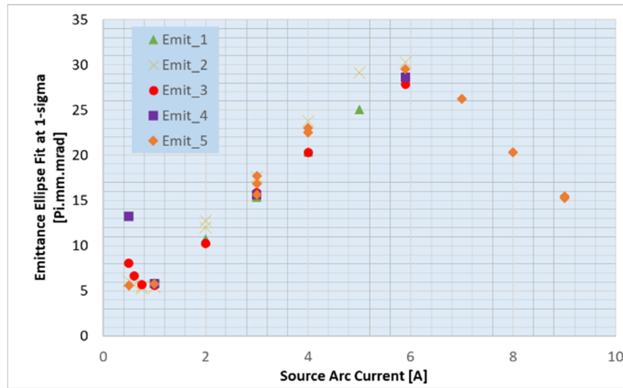

Figure 4: Emittances as given by a 1-σ fit ellipse for five scans of the source arc current performed on different days.

Discussion

Similar values of the emittance are obtained at every start-up of the machine supporting the feasibility to compare the subsequent numerous magnet settings that have been performed. This will be part of the second stage of analysis and includes additional slit use and quadrupole scans, i.e. examination of secondary particles contamination. Though the beam position was not recurrent, revealing the impact of the magnets.

With the increase of the arc current, the (x,x') distribution shows several concentration spots that are turned on and increases. The provenance of the multi-spots has still to be investigated with regard to the source settings. Also the impact of the magnetic environment from the MC on the beam and on the emittance-meter is a subject of investigations.

CONCLUSION

First emittance measurements have been performed with an Allison type emittance-meter at the Arronax injection beamline. The results tackle several inquiries on the complexity of the delivered beam from the source and lead to potential operational optimisation. Further investigations and analysis are being performed at the time of writing. It is expected that this work will bolster future developments such as diagnostics and possible emittance constrain studies.

Additionally, the methodology used to accommodate the emittance-meter, which will be used with other accelerators, contributes to define a protocol for the possible activation follow-up of the device. This protocol can help to engage into similar procedure for the various accelerators and be the base for future exchanges on this matter.

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