Outlook of the application of the PyCAMFT code for the ISOL installation development

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Abstract. Currently the tracking code PyCAMFT, which can be effectively applied for the simulation of the online isotope separators (ISOL), is being developed. The peculiarities and advantages of the code are discussed. The results of the modeling of a multicomponent beam in a simple separator online using the PyCAMFT are given.

1. Introduction
For the needs of low and middle energy nuclear physics radioactive ion beams (RIB) are of particular interest. Currently, two methods of particle separation are used for the RIB production: In-Flight and ISOL (isotope separator online). Both methods are effective, and the choice of the method which would be most suitable for the experiment should be based on the experiment conditions for a specific physical problem. The ISOL method is applied now for the RIB installations in CERN (ISOLDE) \cite{1}, GANIL (SPIRAL) \cite{2}, TRIUMPH (ARIEL) \cite{3}, LNL INFN (SPES) \cite{4}, SCK CEN (ISOL@MYRRHA) \cite{5}. In general, the ISOL method combines the procedures of particle extraction, separation, additional ionization, acceleration, production of secondary ions on the targets, beam transport and transfer. As a rule, the development of any facility based on accelerator technologies begins with numerical modeling which gives the possibility of achieving the necessary parameters and minimize the risks and costs. Choosing appropriate code for such modeling is an important part of facility development. In this paper the PyCAMFT code \cite{6} is proposed for preliminary simulation for the ISOL construction. The peculiarities of the code and the results of the modeling of a two-component beam in a simple ISOL beamline are described.

2. Peculiarities of the code PyCAMFT
A specific feature of the PyCAMFT code is that it uses direct integration of the particle motion equation in arbitrary electromagnetic fields for each particle of the beam. In the code the motion equation (1) is integrated using the Runge-Kutta method of 4\textsuperscript{th} order:

$$
\frac{d\vec{p}}{dt} = Ze(\vec{E} + \vec{v} \times \vec{B}),
$$

(1)
where $\bar{E} = \bar{E}_{ext} + \bar{E}_{in}$, $\bar{B} = \bar{B}_{ext} + \bar{B}_{in}$ - electromagnetic fields, which are self-consistent, $\bar{E}_{ext}$, $\bar{E}_{in}$, $\bar{B}_{ext}$ and $\bar{B}_{in}$ are the external and own beam fields, $Z$ is charge state of the particle, $p$ - particle momentum, $e$ - the charge of an electron. In the PyCAMFT an external electromagnetic field can be set by various methods (tables, functions) while forming the initial data block.

The calculation of the trajectory for each particle increases essentially the full time of calculations, but compared to the PIC-methods this method provides the possibility of improving the accuracy due to the absence of stochastic error, which is inherent in the PIC-based codes [8]. To minimize the time of calculation the optimized scheme of parallel calculations is under development now.

The PyCAMFT is written in Python. Note that the first version of CAMFT code was written in C++. In this version we tested the idea of direct integration of trajectories for each particle [7], but it was the draft version with low functionality.

At figure 1 the current interface of the code is shown. The interface is simple, intuitively understandable and convenient for the developer.

![Figure 1. The code interface window.](image)

3. Numerical solution

PyCAMFT was used to simulate two-component bunch separation by means of simple beamline consisted of one accelerating diode and one bending magnet. The bunch has two species with various charge states of carbon isotope ions ($^{11}$C$^{5+}$ and $^{11}$C$^{6+}$). Note that the radioactive beams are unstable, in particular, isotope $^{11}$C has a half-life ~ 20 min, so the time control of the beam flight in the installation is needed, and PyCAMFT provides such possibility. The quantities of the ion species in the bunch were different: N1/N2 = 3/4, where N1 corresponds to the ions with charge state 6+, N2 corresponds to the ions with charge state 5+. The field distributions were determined by means of the functions. The voltages of the accelerating diode were taken equal to 100 kV and 1 MV. Magnetic fields were taken in the range 0.01 T - 1 T. The calculations were carried out for various beam temperatures ranging between 0.1 eV - 2 eV.

At figure 2 the integral particle distributions at the virtual detector are shown, calculated for the case of magnetic field of a static separator equal to 1 T. The position of the virtual detector corresponded to the turn angle $180^\circ$. The accelerating voltage of 100 kV was taken. Beam temperature was 0.1 eV. Initial bunch energy spread was 5%. The calculated distributions allow to evaluate the
resolution of the ISOL easily. The best resolution achieved in the numerical experiment was \( \Delta m/m = 5.4 \times 10^{-4} \).

**Figure 2.** Calculated particle distributions of two-specie bunch (\(^{11}\)C\(^{5+}\) and \(^{11}\)C\(^{6+}\)) after passing the separator. Voltage is 100 kV, magnetic field is 1T. Bunch energy spread is 5%. The turn angle is 180°.

**Figure 3.** Bunch particle distribution at the virtual detector in the case of sheet bunch geometry. **Figure 4.** Bunch particle distribution at the virtual detector in the case of axial symmetric bunch geometry.

Figures 3 and 4 show the intensity distribution of one species of the bunch (corresponding to the charge state 5+) at the plane of virtual detector, placed at the entrance to the bending magnet field. Figure 3 corresponds to the bunch extracted from ion source through the slot. Calculations confirm the known fact that the slot geometry of the extraction hole is preferable to achieve better resolution. Some experiments may require the shape of the bunch to be axially symmetric. In figure 4 the initial distribution of the particles of one species (5+) is shown for the case of axial symmetry of the bunch. In both cases the bunches have finite temperature of the particles equal to 2 eV. The Maxwell distribution of the particles in the velocity space and Gaussian distribution in the coordinate space were accepted while forming the initial data block. Note, that the PyCAMFT can handle non-Maxwellian and non-Gaussian distributions too.

**4. Conclusions**

Modern ISOL installations include various accelerator units (particle sources, separators, ion traps, high-voltage diodes, optics, targets, RF-cavities). The peculiarity of such installations is relatively low energy of the ions, so the effect of the bunch own space charge dominates. For simulating such
installation beamlines the PyCAMFT code can be very efficient, since the PyCAMFT does not accumulate the stochastic errors inherent in PIC-based codes. The ability of the PyCAMFT to handle arbitrary beam geometry, arbitrary spatial and velocity distributions of the beam particles and arbitrary electromagnetic fields can be applied while creating the various facilities with ISOL. The visualization tools of the code allow to estimate the ISOL resolution easily. The PyCAMFT tool of easy control of the beam flight time during the simulation is important for the developer because of restricted lifetime of radioactive ion beams. One more feature of the code, namely, the ability to control the beam parameters by means of virtual detector, create the additional convenience for the developer. In the paper the results of the modeling of a beam of carbon isotope ions with two charge states using the PyCAMFT are presented for the case of a beamline consisting of two accelerator units. The results demonstrate some of the code features.

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