# NORTICA – A NEW CODE FOR CYCLOTRON ANALYSIS

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## 1. Introduction

The CCF project that is in the commissioning stage at NSCL requires new software for the development of heavy ion beams. A specific feature of this project is that both cyclotrons K500 and K1200 should be set simultaneously and interdependently.

The new package was developed based on the programs and algorithms created in the laboratory in the past for a single cyclotron simulation [2]. These original programs were generalised in order to accommodate features of both cyclotrons. All the differences between the two machines are expressed in the input and output data, so the codes accept a specific set of input data and generate a set of corresponding results.

Fortran programming language was used for the numerical algorithms realization, Tcl/Tk – for the user interface and C for the program interface.

## 2. Schematic CCF Cyclotrons Setting Procedure

The CCF setting procedure starts by choosing the appropriate charge states of the ion in both cyclotrons for the given final energy. This task is performed with the OPERCOUP code. The next step is to set the K1200 cyclotron for the given ion and for the desirable final energy. The RF frequency is fixed at this point by the extraction energy. After the finalizing of the K1200 setting, the K500 is simulated. Instead of fixing the K500 final energy (injection energy for K1200) one has to fix the RF frequency for the K500 to the same value as the one for the K1200. The injection beam energy to the K1200 remains unknown until the K500 is set, so the detailed injection using code INJORBEX [3] is done after setting both cyclotrons.

The present paper describes the codes used for the setting of the cyclotrons for CCF operation. The same codes can also be used for the stand-alone operation setting any of the cyclotrons.
The package consists of three major parts.

The first part includes procedures for fitting main and trim coil currents in order to shape the main magnetic field.

The next part provides the actual beam dynamics simulation in the previously generated field with imperfections and additional contributions to the total magnetic field (extraction elements and bumps).

The last part involves the detailed simulation and setting of the extraction system parameters.

The result of the extraction system setting is needed both for the first and second stages, so the setting procedure is actually iterative. This effect is especially strong in the K1200 cyclotron where due to a smaller turn separation the extraction elements more strongly influence the internal beam dynamics than in the K500.

## 2.1 K1200 Cyclotron Setting

The part of the NORTICA package that is responsible for setting the main and trim coil currents for the K1200 or K500 cyclotrons is called MFIT. The computer screen with this code running is shown in Fig. 1. As an example, the ion of $^{40}Ar^{18+}$ with the final energy of 140 MeV/u is considered in these calculations.

The input set of data includes a relatively small profile data file that has general cyclotron and ion information and references to additional files. The major part of the input data is the set of field maps measured with different settings of the main coil currents and also measured trim coil contribution maps [4,5]. The other information includes spiral gap geometry, dee voltage profile with dependence on the frequency, extraction elements geometry, bumps, etc. All of this information is presented in a general form common to both cyclotrons.
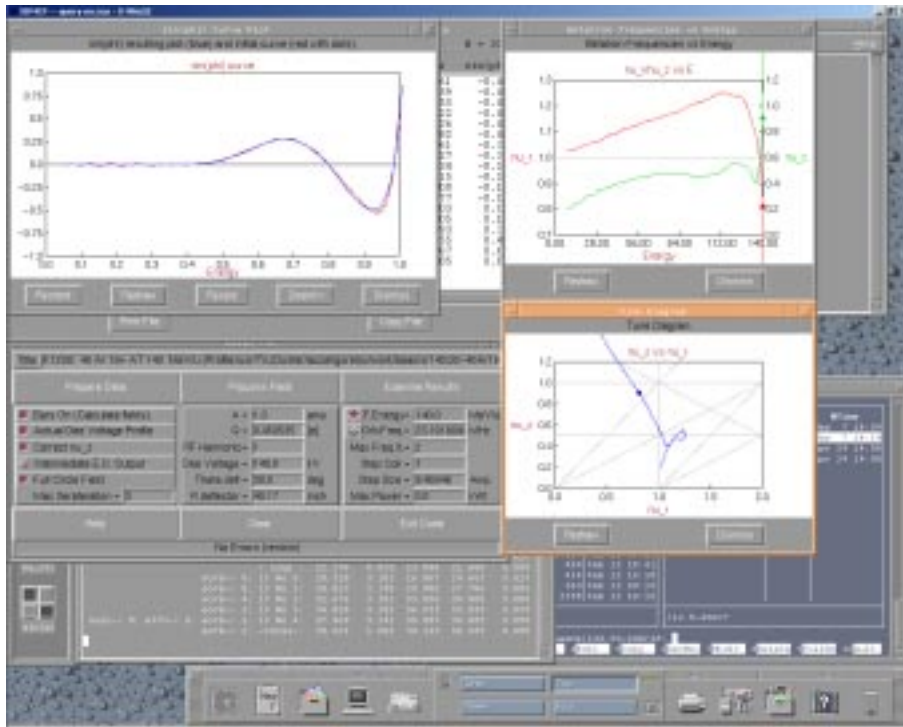
Figure 1: Typical screen of NORTICA-MFIT code output for $^{40}Ar^{18+}$ ion. The panel in the left-bottom corner has all main input parameters used for the fitting. The left-top corner shows the requested and resulting sin(phi) curve. On the right the transverse oscillation frequencies as function of energy (top) and tune diagram (bottom) are presented.
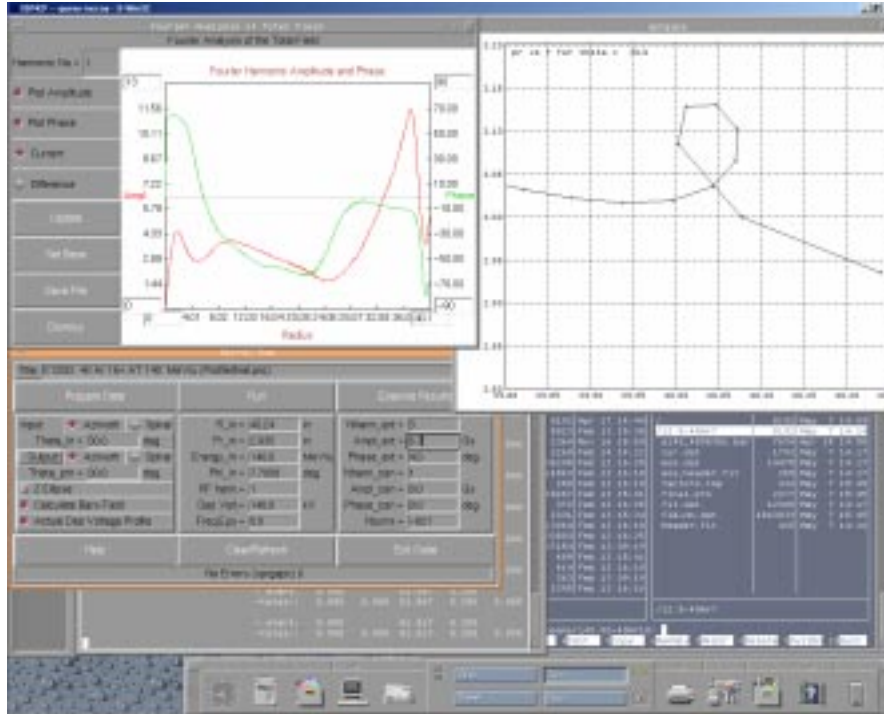


Figure 2: Typical screen of NORTICA-SPRGAP code output for $^{40}Ar^{18+}$ ion. The panel in the left-bottom corner has all main input parameters and settings used in this session. The left-top corner shows the first fourier harmonic amplitude and phase of the total field. The right-top corner has an r-pr plot of the beam centroid over last several turns at the extraction azimuth.

When the satisfactory field characteristics are achieved the resulting magnetic field from the main coils, trim coils, and iron is assembled and saved for use in the next stages.

The next step is setting the extraction bump and checking the beam centroid dynamics in the cyclotron. This task is done with the help of the NORTICA-SPRGAP code. A typical screen is shown in Fig. 2.

After finding the adequate setting of the extraction bump, the last part of the package (NORTICA-DEFIN) is executed. At this stage the position of the particular extraction elements, namely the electrostatic deflectors and the focusing bars, and the current for the extraction dipole are set. The example screen of this code is shown in Fig. 3.

## 2.2 K500 Cyclotron Setting

When the K1200 cyclotron is set, a similar procedure is performed for the K500 cyclotron. The same codes, MFIT, SPRGAP, and DEFIN, are executed using the different profile, usually in a different subdirectory.

The fitting now is done with the fixed frequency instead of the fixed output energy and for a different charge state of the same ion (in the case of the above example of Argon beam it would be $^{40}Ar^{7+}$). The results are saved in a similar format but for the different set of parameters.

## 3. Conclusion

The friendly user interface allows the user to see clearly the beam and field characteristics dependence on different input parameters that makes the process of the cyclotron setting quicker. However, the current experience shows that the setting suggested by the code requires correction when applied for the machine. The main magnetic field value should be changed in order to preserve the fixed RF frequency by about 0.0003 in relative values. We think that the difference in magnetisation of the pole-tips and yoke iron changes slightly with the temperature that produces the overall effect.
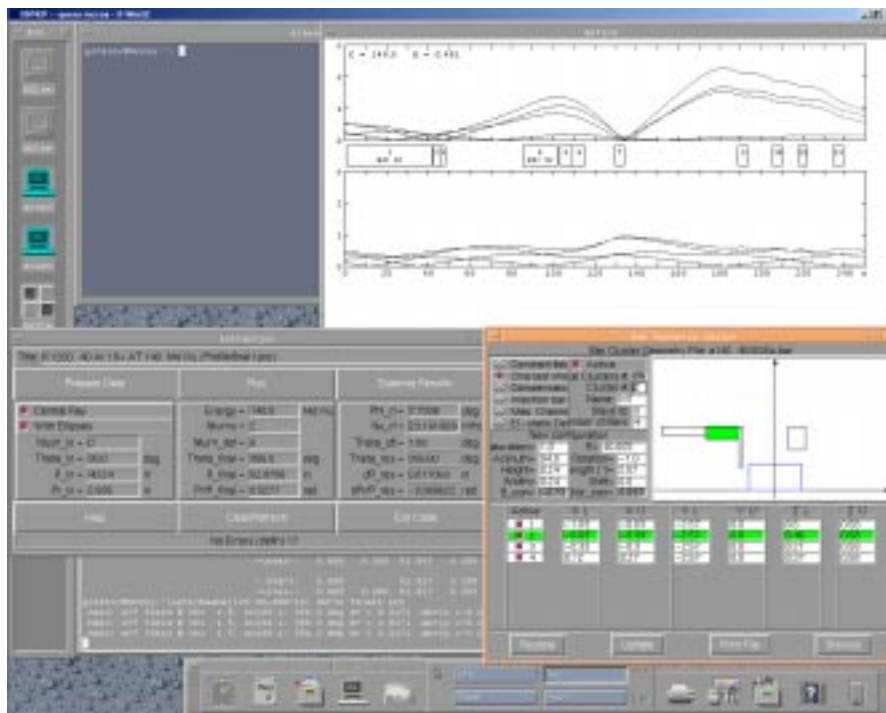


Figure 3: Typical screen of NORTICA-DEFIN code output for $^{40}Ar^{18+}$ ion. The panel in the left-bottom corner has all main input parameters and settings used in this session. The right-top corner shows the representative envelopes of the beam along the extraction path. The right-bottom corner shows the editor screen for one of the focusing bars clusters.

References

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[4]      L. H. Harwood et al., "Magnetic Field Measurements of the NSCL K800 Cyclotron Magnet", Proc. Of 11$^{th}$ Int. Cyc. Conf., (1986) Tokyo, p.315.

[5]      P. Miller, et al, "The Magnetic Field of the K500 Cyclotron", MSUCP-37, East Lansing, January 1982.