FINAL REPORT

on

ACCORD
on a Software Development for Electron Cooling Simulation
and Experimental Studies of the Cooling Process in the Recycler ring

between

Fermi National Accelerator Laboratory (FNAL)
Batavia, IL 60510, United States of America

and

Joint Institute for Nuclear Research (JINR)
141980 Dubna, Russian Federation

Under this accord JINR provided source-codes for simulation of the electron cooling and stochastic cooling processes within the frame of the BETACOOL program, installed this program at FNAL, prepared all the required initial files and performed various simulations of the cooling process in the Recycler ring.

The basis for this Accord was to introduce in the code new options for calculating the cooling process taking into account the peculiarities of the Recycler cooling systems. Two of the main new features are the added capability for calculation of the longitudinal dynamics with barrier buckets and the implementation of a new algorithm for gated stochastic cooling. Benchmarking of the code for longitudinal dynamics calculations was performed by comparing test cases with the results from the ESME code (extensively used at FNAL). In addition, validation of the program included the participation of JINR personnel in some cooling experiments in the Recycler ring and comparison of the experimental data with simulations. JINR developed the interface of the program for the new options and provided updated manuals with a complete description of the code and the physics models. Finally, JINR provided all the input files, which were used to perform the benchmarking and validity tests.

The following items of the specifications document were done (or updated) in the frame of this Accord (G – means Physics Guide, M – means User Manual):

I. Input

Input files contain the following information.

1. Lattice functions in the format of the MAD program [M.VII.2.1.].
2. Stationary (in time) RF waveform and moving (in time) barrier bucket model [M.VII.1.6].
3. Electron beam distribution [G.II.4.1, M.XI.2].
4. Initial antiproton distribution over three actions [M.VI.1.2]
    a. Particles are assumed to be distributed evenly over phases
    b. The distributions can be described either by an input file or by standard functions

II. Effects

The code is capable of taking into account, together or separately, the following effects:

1. Bunching of the antiproton beam. Separate modes are foreseen for [M.VII.1.6]:
    a. Simulation of the beam in a finite height rectangular RF bucket
    b. Simulation of the beam with sinusoidal RF structure [numerical approximation]
    c. Simulation of the beam with any shape of RF waveform [numerical approximation]
2. Electron cooling [G.II.4.1, M.XI.2]:
    a. Properties of the electron cooling are calculated from the following electron beam properties: current density, r.m.s. angle, r.m.s. energy spread, and energy mismatch.
    b. The electron beam properties are averaged over time and the length of the cooling section.
    c. The radial dependences of the current density are described either by input files or by standard functions.
3. Stochastic cooling. [G.IV, M.XII.2]
    a. The gain is longitudinally gated, with at least 4 regions with independent gain.
    b. The gain is time-dependant, and is read from an external file.
        i. The scope of this item was slightly modified and agreed upon.
4. Residual gas scattering. [M.X]
5. Intrabeam scattering (IBS) in the antiproton beam [M.VIII, G.III]
    a. IBS simulation is performed using either a standard algorithm for mean growth rate calculation or algorithms for “detailed” rate calculation developed at FNAL and BNL.
6. Heating by the damper noise is represented by an additional constant transverse diffusion. [G.I.1.3, G.I.2.5]
7. Effects of RF noise and MI ramping are represented either by constant diffusion or by a file including the dependence of the diffusion on the longitudinal action. [G.I.1.3, G.I.2.5]

III. Output

1. The output properties include the following [M.VI.2]:
    a. Transverse spatial distribution
    b. Density distribution along the bunch
    c. Momentum distribution
    d. Number of particles
    e. Average momentum
2. For each distribution, the following parameters are calculated [M.VI.2, MVI.1.1]:
    a. R.m.s.
    b. Sigma of a best-fitted Gaussian distribution
    c. Boundary value of 95% of particles
3. A temporal evolution of each of the parameters above can be displayed in a graphical form or saved into a file. [M.I.1.4]
4. Capability of outputting the data at different times along the simulation [M.I.2]

IV. Software requirements

The developed software includes the source code, the executable module, an interface part, and satisfies the following conditions:

1. The source code is platform-independent, object-oriented, written in the ANSI/ISO standard of C++ language and supplemented by annotations to simplify understanding and possible alterations.
2. The executable module is prepared in two versions: for WINDOWS and LINUX operational systems.
3. The interface part works under the WINDOWS operation system (WINDOWS XP and VISTA) and provides editing capabilities of input files and visualization of the output data on line with calculations.

In accordance with the terms of the Accord, several documents, other than the updated manual and physics guide, were written and summarize the main features added to the code, their functionality and the way to use them through examples. These documents include results from simulations and comparisons to other codes (for benchmarking) or experimental data. They will be included to the Accelerator Division Database (public) along with this report.

As such, this report (along with the additional documents described above, the source-code, manual and physics guide, and example input files) concludes the Accord between JINR and FNAL.