Simulation of Beam Optics and Beam-Degrader Interaction for COMBAS Fragment-Separator

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Abstract

COMBAS is a dedicated high-resolution large solid-angle and momentum acceptance fragment-separator to be installed at Flerov Laboratory, JINR. It provides independent separation of isotopes in A and Z using magnetic analysis combined with different stopping powers of particles in a profiled degrader at the dispersive focal plane. Results of simulations illustrating predicted performance of COMBAS including correction for nonlinear effects in beam optics and optimization of the degrader shape are given in the paper.

1 INTRODUCTION

The COMBAS projectile-like fragment-separator is being constructed at the Flerov Laboratory of Nuclear Reactions for experiments with intermediate energy heavy ions accelerated by the U-400M cyclotron or the tandem of the U-400 and U-400M cyclotrons. The U-400M cyclotron accelerates rare neutron rich isotopes up to 50 - 60 MeV/A with intensity of about 10^{13} pps.

Our design efforts were mainly concentrated on a high resolution power of separation and high efficiency of collecting exotic nuclei which are produced in a wide energy and angular range. The program of experiments requires the following properties of the COMBAS fragment-separator: (i) — ions with magnetic rigidity up to 4.5 T-m should be accepted ; (ii) — The separator should be achromatic, in the middle of the channel dispersion of the particles with different magnetic rigidity should be provided with the resolving power being greater than 4000. Installation of a thin degrader foil at this point should lead to separation of ions of equal magnetic rigidity, but different in mass; (iii) — Angular and momentum acceptances of the system should be as large as possible taking into account technical and economical problems.

Ion-optical design of the COMBAS was presented in [1]. Results of our simulations have shown solid angle acceptance of the separator to be equal to 6.4 msr, momentum acceptance is about ±6% at full solid angle. One of the main problems while dealing with such large values of angles and momentum spread is to suppress nonlinear distortions in beam optics. The other problem arises when a degrader is installed at the point of intermediate focus because it influences the beam as a nonlinear dissipative ion-optical element. The present paper shows the results of our simulation of beam optics of the COMBAS separator including beam-degrader interactions.

2 BEAM OPTICS OF THE COMBAS

A schematic layout of the COMBAS magnetic system, beam envelopes and momentum dispersion function are shown in Figure 1. The doubly achromatic magnetic system includes an analyzing section and a dispersion compensating section, which are exactly mirror symmetric with respect to the middle point of the system. The focusing of the beam is produced by alternating gradient of magnetic field in the magnets M_1 and M_2, which focus particles in the y-plane (vertically) and x-plane (radially) respectively. The magnets M_3 and M_4 form a system for parallel beam horizontal shift. This makes it possible for optical functions to be symmetrical in both sections of the system.

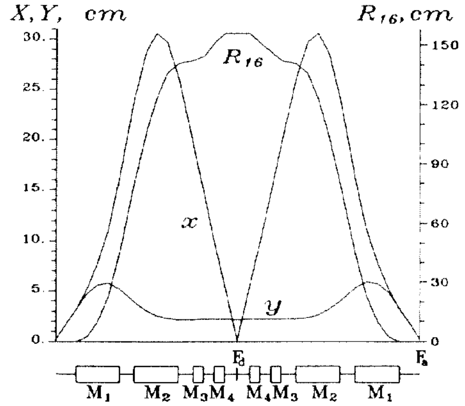

Figure 1: Schematic layout of the COMBAS, $x-$ and $y-$envelopes, and momentum dispersion function R_{12}. F_d is the intermediate dispersive focus point, F_a is the achromatic focus point.

It has been shown [1] that in order to be capable of achieving high COMBAS resolution power, special care should be taken for optical aberrations. Nonlinear effects in beam optics lead to substantial reduction in resolution.

The first-order resolution can almost be recovered by introducing the sextupole component in all of the magnets and curving entrance and exit effective field boundaries of dipoles M_3 and M_4. Octupole component should be also introduced in the magnetic field. Figures 2 and 3 present results of correction for nonlinear effects. When solving this problem mirror symmetry of the magnetic system was preserved with respect to high-order field components. A detailed description of the magnet design is presented in [2, 3].

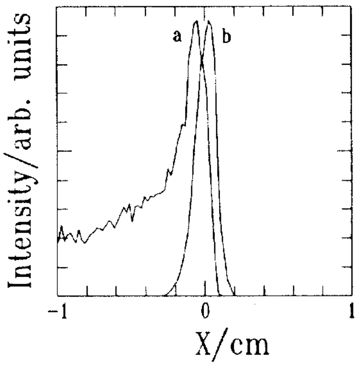

Figure 2: Intensity distribution of a zero-momentum offset fraction of the beam at the point of dispersive focus before (a) and after (b) correction for nonlinear distortions.

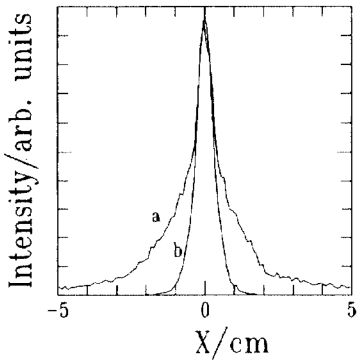

Figure 3: Intensity distribution of the beam with uniform ±6% magnetic rigidity spread at the achromatic focus point before (a) and after (b) correction for nonlinear distortions.

3 BEAM OPTICS WITH THE DEGRADER

It is a well known fact that a lot of nuclei of different sort having the same magnetic rigidity is produced by the primary beam passing through the target. It is impossible to separate the nuclei of interest out of contaminants using an ordinary magnetic separator. A special isotope separator consisting of an achromatic magnetic system with an energy degrader located in the intermediate focal point can be used for this purpose [4].

We have used this conception of "momentum-loss achromat" in designing the COMBAS. The degrader is to be placed at the point F_d of intermediate focus. The crucial point for such type of a separator is the profile of the degrader foil. Its width should be chosen so as to provide separation of isotopes of different sort at the pont of the achromatic focus. The profile of the degrader should be optimized to preserve achromaticity of the magnetic system minimizing energy and angular straggling of ions at the same time. Achromaticity of the degrader means that the dispersion matching before and after the degrader is not disturbed. It should be pointed out that the width and the profile of the degrader depend on the particular nuclei to be separated out of contaminants.

We have developed a computer code to provide degrader optimization and study beam optics with the degrader. Beam optics before and after the degrader is treated using a matrix formalism including non-linear effects up to the third order. Beam passing through the degrader is simulated by a Monte Carlo algorithm including extended Bethe-Bloch stopping-power formula [5, 6].

Table 1 gives some results of degrader optimization for separation of isotopes produced by the reaction of 44 MeV/A argon primary beam with the berillium target of the thickness of 99 mg/cm^2. The material of the degrader was chosen to be aluminium to minimize effects of electron captures and secondary reactions and to provide the required accuracy of the degrader profile while manufacturing. Initial spatial distribution of ions was supposed to be uniform within the acceptance of the separator: $x^2 + y^2 \leq r^2$, $r = .25\ cm$, $p_x^2 + p_y^2 \leq p^2$, $p = .04\ rad$.

Intensity distributions of isotopes at the point of achromatic focus for the cases listed in Table 1 are presented in Figures 4–7. The required separation of the nuclei of interest is clearly shown.

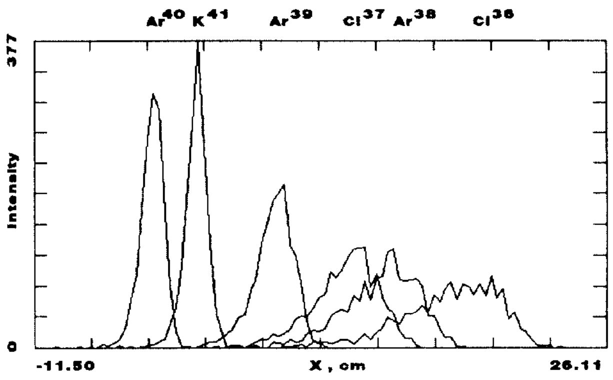

Figure 4: ^{41}K separation

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Table 1: Results of degrader optimization for separation of isotopes produced by the reaction of 44 MeV/A argon primary beam with the berillium target of the thickness of 99 mg/cm^2

Fragment to be selected	Contaminants	$B\rho$ (T-m)	Degrader thickness (mm)	Wedge angle (mrad)
^{41}K	^{40}Ar ^{39}Ar ^{38}Ar ^{37}Cl ^{36}Cl	1.77 ±1.7%	.3	.67
^{38}Ar	^{41}K ^{40}Ar ^{39}Ar ^{37}Cl ^{36}Cl	1.77 ±1.7%	.35	.76
^{39}Ar	^{40}Ar ^{38}Ar ^{38}Cl ^{37}Cl	1.81 ±1.7%	.35	.78
^{39}Cl	^{37}S ^{36}S ^{38}Cl ^{40}Cl	1.94 ±1.3%	.42	.94

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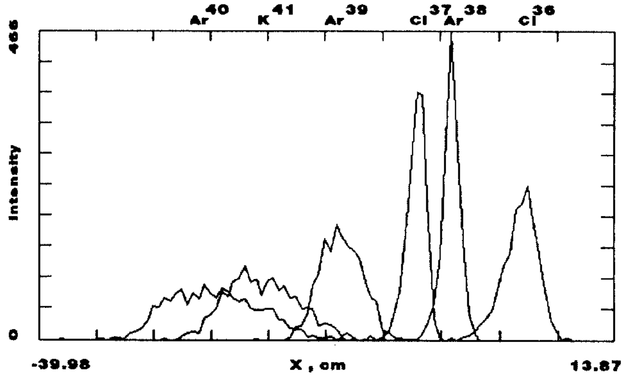

Figure 5: ^{38}Ar separation

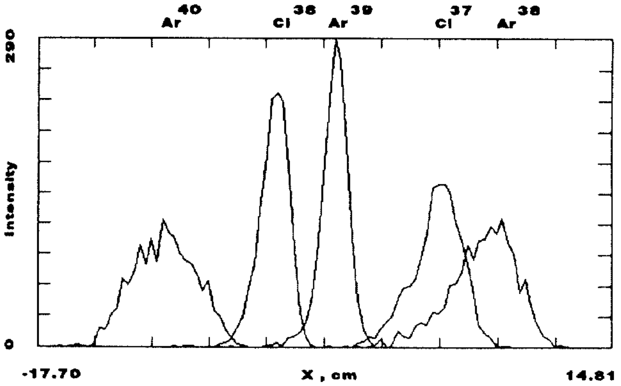

Figure 6: ^{39}Ar separation

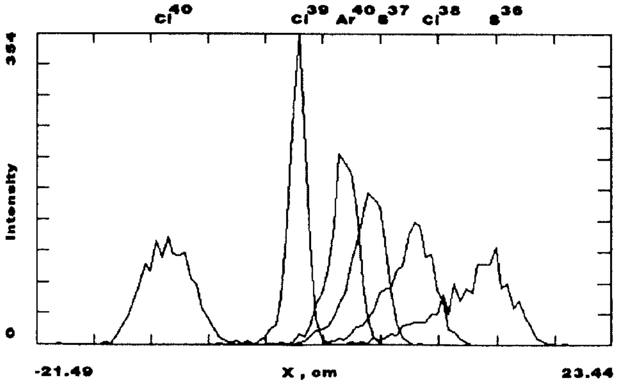

Figure 7: ^{39}Cl separation