ION SCANNING SYSTEM IN BEAM LINE OF U-400M CYCLOTRON FOR ELECTRONIC COMPONENTS TESTING[†]

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Abstract

The beam line of the U-400M cyclotron is designed for irradiation of chips by beams of accelerated ions to determine their radiation resistance. The results of the beam transport calculations for various ion types taking into account the beam parameter changes on passing a collimator and degrader are presented. The resulting beam sizes on a target are obtained for all beam variants. The calculated beam size on the target varies in the range from 15 cm up to 30 cm. An analysis of three variants of the magnetic scanning system is carried out. The working scheme, construction and main technical characteristics of the optimal variant are presented.

INTRODUCTION

The beam line of the U-400M cyclotron is intended for the chip irradiation by flows of the accelerated ions for determination of the radiation influence upon chip work. Parameters of the ions that are supposed to be used in this beam line are presented in Table 1[**1**].

Table 1: Parameters of the ions

Ion	W_0 [MeV/amu]	A	Z_{ext}	A/Z_{ext}
Ne	9.2	22	+10	2.2
Ar	7.8	40	+17	2.35
Kr	8.8	86	+33	2.61
Xe	8.8	136	+49	2.78

Calculations of the beam tracing in the beam line for the beam parameters, specified in Table 1, were carried out in this work. The turned out beam dimensions on the target were defined. The different variants of the scanning system for getting demanded uniformity of the beam density distribution on the target were investigated.

BEAM LINE SCHEME

The beam line scheme is shown in Figure 1. The main beam line elements are: the correcting magnet B5CMV1 (B5CMH1), the horizontal scanning magnet B5SMH1, the vertical scanning magnet B5SMV1, the diagnostics block B5BD1 and device in the beam line end where the target is placed. The iris is placed between corrector and horizontal scanning magnet. The length of both scanners is equal to 600 mm; their bore diameter is equal to 90 mm. In the diagnostics block there is a device having the set of tantalum foils. The energy of the accelerated and extracted from the cyclotron ions can be diminished with

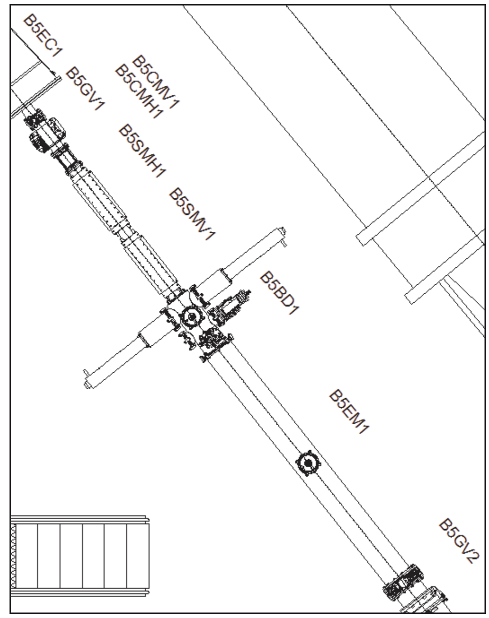

Figure 1: Scheme of the beam line

the help of these foils down to three chosen intermediate values of 6 MeV/amu, 4.5 MeV/amu and 3 MeV/amu.

Calculation of the ion movement in the beam line was carried out with the help of the code COSY INFINITY [**2**] in assumption that the beam has the Gaussian density distribution in its cross-section. One considered also that the magnetic fields of the scanners were switched off and the particle movement from the extraction point to the target occurs in a free space. In this case the initial data for COSY INFINITY code were calculated from the initial values of the second order moments $\overline{x^2}$, $\overline{(x')^2}$, $\overline{xx'}$, $\overline{y^2}$, $\overline{(y')^2}$ and $\overline{yy'}$ [**1**]. All dispersions and their derivatives were considered to be equal to zero. The magnitudes of the initial moment values for the set of ions specified in Table 1 are presented in Table 2. The value of the initial relative root-mean-square spread of the ion longitudinal momentums δ_0 is equal to 2.49 10^{-3}

The total length of the beam line is equal to 622 cm. There is an iris at the distance of 139 cm from the point of the beam extraction. The tantalum foil having the diameter of 90 mm is placed at the distance of 155 cm from the iris.

Evaluations show that maximum beam deviation on the foil, when the scanners are turned on, amounts ~30 mm. Therefore the beam radius before the foil must not exceed 15 mm in order the beam will not exceed the foil bounds on scanning. From these considerations the iris diameter was chosen equal to 20 mm.

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Table 2: Initial moment values

Ion	$\overline{x^2}$ [cm²]	$\overline{(x')^2}$	$\overline{xx'}$ [cm]	$\overline{y^2}$ [cm²]	$\overline{(y')^2}$	$\overline{yy'}$ [cm]
Ne	1.95	9.31 10^{-5}	1.35 10^{-2}	6.19 10^{-3}	2.37 10^{-5}	3.65 10^{-4}
Ar	2.03	9.75 10^{-5}	1.41 10^{-2}	6.90 10^{-3}	2.57 10^{-5}	4.05 10^{-4}
Kr	1.85	7.93 10^{-5}	1.81 10^{-2}	5.74 10^{-3}	2.16 10^{-5}	-3.25 10^{-4}
Xe	2.33	9.15 10^{-5}	1.46 ``10^{-2}	2.44 10^{-2}	2.94 10^{-5}	-8.15 10^{-4}

Dimensions of the irradiated chip is equal to 50 × 50 mm². But because of the diagnostics, that must be placed around the target and control uniformity of the beam density distribution on it, the region where non-uniformity of the beam density distribution must not exceed the value ±5% was enlarged to the value of 100 × 100 mm².

Calculation of changes of the ion beam parameters on its passing through the iris was carried out by procedure stated in **[3]** and calculation of changes of the ion beam parameters on its passing through the degrader foil was carried out by procedure stated in **[4]**.

The calculation results of the Ne ion transportation are shown in Figure 2. The solid curves correspond to the beam horizontal dimension and dotted ones correspond to its vertical dimension. The tantalum foil thickness was selected so as to diminish the initial beam energy down to its final values W = 6, 4.5 and 3 MeV/amu.

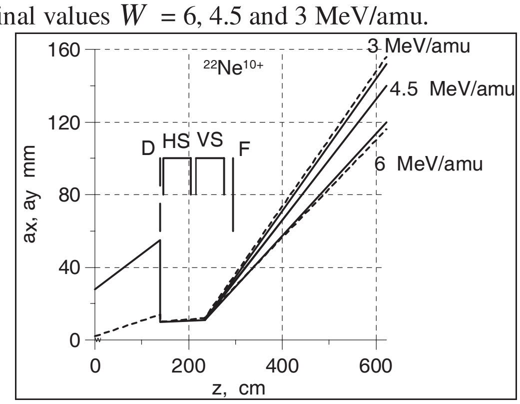

Figure 2: Calculated envelopes of the 22Ne10+ ion beams in the beam line. Here D is the iris, HS is the horizontal scanner, VS is the vertical scanner, F is the tantalum foil

For the considered ion set the calculated beam radius on the target possesses the value from ~75 up to ~159 cm. But necessary uniformity of the beam density distribution on the target can not be obtained without the scanning system.

RESULTS OF SCANNING SYSTEM WORK SIMULATION

Work of the following three variants of the scanning system was investigated:

1. The scanners having the sawtooth feed and frequencies f_x = 110 Hz, f_y = 100 Hz.
2. The scanners having the sine-shape feed at the frequencies $f_x = f_y$ = 50 Hz and the phase shift by $\pi/2$ (circular sweep).
3. The scanners having non-linear sawtooth feed and frequencies f_x = 10 Hz, f_y = 11 Hz.

The carried out analyses showed that when the beam dimensions were sizeable and determined in main by thickness and type of the foil, the variant 2 is the most optimal. Moreover, only this variant provides the necessary uniformity of the beam density distribution on the target for all ion types and energies under conditions of the mean current limitations in the magnets. Besides, the circular sweep allows one to correct small differences in width of the horizontal and vertical dimensions due to independent setting of the scanner field amplitudes.

The calculated distributions of the $^{22}Ne^{10+}$ ion density (W =3 MeV/amu) on the target in arbitrary units for scanners operating at the highest possible amplitudes $J(x)$ (upper curve) and also the beam density distribution on the target when the scanners are turned off $F(x)$ (lower curve) are shown in Figure 3.

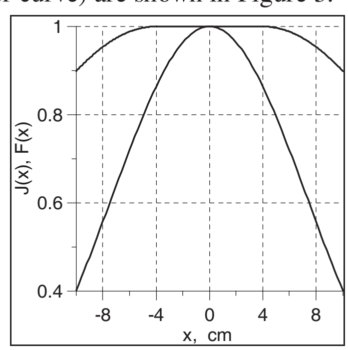

Figure 3: Calculated distributions of the ion density on the target along horizontal with (upper curve) and without (lower curve) scanning

STRUCTURE OF SCANNING SYSTEM

The scanning system consists of two deflecting magnets, power supply unit and control unit.

Construction of the deflecting magnet represents a distributed winding located directly on the ion beam line surface surrounded with compactly fitting bladed magnetic circuit made of electrical-sheet steel. The turn density of the winding vary through the azimuth according to cosine low that allows one to obtain high magnetic field uniformity in all volume of the ion beam line.

The construction of both magnets is identical but they are rotated one relative to another through an angle of 90^0. The magnetic field non-uniformity in the region of supposed beam dimensions does not exceed ±5%. Full heat losses in the magnet do not exceed 300 W, part of them falls on heat of the ion beam line made of thin-wall stainless steel.

Parameters: maximum deflecting magnetic field B in both magnets is equal to 400 Gs; the scanning frequency f = 50 Hz; length of both magnets along the magnetic screen l = 660 mm; maximum peak current in the windings I_{max} = 14 A; cooling of all magnet windings is carried out by the air forced method.

Appearance of the magnets is shown in Figure 4.

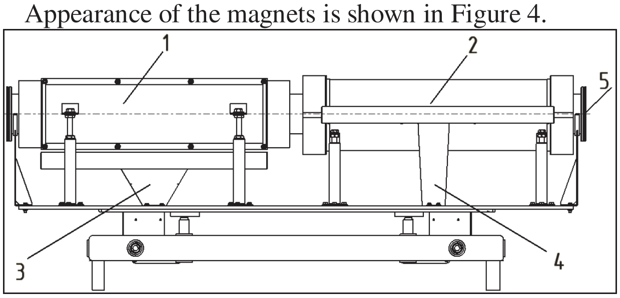

Figure 4: System of the circular sweep: horizontal scanner (1), vertical scanner (2), air conduits (3,4), vacuum ion beam line with flanges (5).

The functional scheme of the equipment power part is shown in Figure 5.

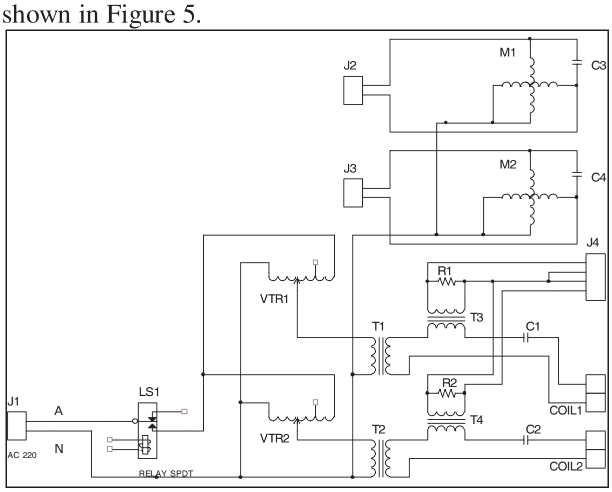

Figure 5: Power module functional diagram

Functionally power module consists of the following units: scheme of hand and remote commutation of the single-phase alternating current net; two single-phase voltage regulators remotely-operated with the help of two alternating current engines; two power step-down transformers; two measuring current transformers; phase-shifting capacities C1 and C2.

The control module is fulfilled as a printed circuit board 220×100 mm^2 where all module components are placed. The printed circuit board is located in the standard module Euro-191 Rack Mount having the width of the front panel 42TE and its height 3U. Access to the inputs and outputs of the module is carried out through contacts of two D-SUB9 and one D-SUB25 connectors placed on the back module panel.

Functionally the module consists of (Figure 6):

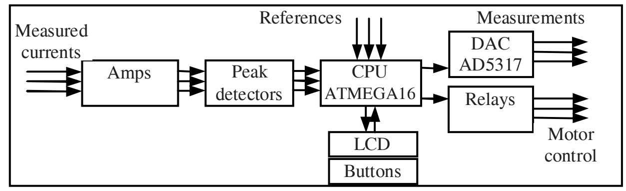

Figure 6: Control module functional diagram

microcontroller Atmel ATMega16 with built-in analog-digital converter (ADC); amplifiers of the current signals in the windings; peak detectors with control; digital-analog converter AD5317; LCD display, buttons and toggles on the front panel; electromagnetic relays.

Sine-shaped signals with frequency 50 Hz from the current transformers, inserted in the deflecting magnets windings, are filtered, amplified by factor 40 and detected by peak detectors controlled by CPU. The microcontroller program initiates ADC measurements every 25 ms measuring current amplitudes in the windings and references specified by external control system. After carrying out measurements, microcontroller discharges the peak detectors providing detection of the current amplitudes in the next measurement cycle. The measured values of the current amplitudes in the deflecting magnet windings are compared with references specified by the outside control system or manually by knobs placed on the front panel. In accordance with measurement results the microcontroller switches on the proper relay to commutate AC voltage to corresponding auto transformer engine, attaining the necessary current amplitude in the windings.

SUMMARY

The scanning system was successfully tested in the cyclotron run for the chip irradiation during more than three weeks. Measurements of the ion density distribution uniformity on the target showed its agreement with the calculations.

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