CALIBRATION OF MEASUREMENT OF ABSOLUTE DEE VOLTAGE FOR U-400M ISOCHRONOUS CYCLOTRON AT FLNR JINR

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Abstract

Results of measurement of absolute dee voltage of the isochronous cyclotron U-400M at FLNR JINR are presented. X-ray technique was applied for measurements. Measurements were made at the following frequencies of the resonance system: 12.8, 13.317, 15.012, 15.1 and 17.5 MHz. To accurately determine the maximum energy of X-ray spectrum, a modeling of X-ray spectrum was carried out by the software package FLUKA. An influence of the absolute dee voltage on the capture factor was estimated by the program Center.

INTRODUCTION

The direct measurement of dee voltage on cyclotrons by the method of adding additional measuring circuits to the resonant circuit is convenient for operational work, but it does not give reliable results for the all frequency range of RF-system of cyclotrons. To adjust a cyclotron to the ion acceleration mode with minimal losses in the central region (the maximum capture factor of the beam acceleration) and to ensure the centering of the accelerated beam, the amplitude of the RF voltage on dees must correspond to the calculated value. The measuring circuits must be calibrated to determine the actual dee voltage. For calibration, a technique for measuring the spectrum of bremsstrahlung X-rays can be used.

Electrons escaping from the surface of DEE and liner are accelerated in the RF field and emit a bremsstrahlung spectrum when hitting a metal surface. The endpoint energy of the spectrum is a measure of peak DEE voltage [1].

THE CONTROL OF DEE VOLTAGE BY PICK-UP ELECTRODES

Measurements were carried out on an isochronous cyclotron U-400M FLNR, JINR. The frequency range of U-400M: f_a = 11.5÷24 MHz, the calculated value of the dee voltage is Ud = 130 kV. The operational control of the dee voltage on the U-400M is made by 8 pick-up electrodes on each dee, located 4 on the top and 4 on the bottom (Fig. 1). The electrical scheme of dee voltage controlling by using pick-up electrodes is shown in Fig.2. The purpose of this work was to measure the actual voltage on dees and calibrate the voltage control circuit with pickup electrodes.

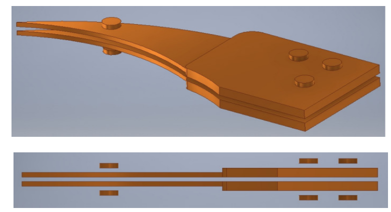

Figure 1: The sketch of dee and pick-up electrodes for measuring of dee voltage.

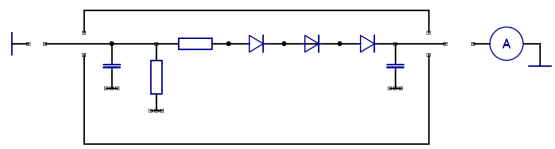

Figure 2: The electrical scheme of dee voltage controlling by using pick-up electrodes.

X-RAY SPECTRUM MEASURING

The XR-100CdTe detector was used to measure X-ray from dees of U-400M. The digital pulse processor PX5 was used to data acquisition (Fig. 3).

The XR-100CdTe is a high performance x-ray and gamma ray detector, preamplifier, and cooler system using 5 x 5 x 1 mm Cadmium Telluride (CdTe) diode detector mounted on a two-stage thermoelectric cooler. The XR-100-CdTe is capable of detecting energies from a few keV to several hundreds of keV, with an efficiency that peaks from 10 to 100 keV [2].

The PX5 includes Digital pulse shaping amplifier , Integrated multichannel analyzer and Power supplies.

The XR-100CdTe was calibrated with radioactive isotope of ^{180}Ta (Fig. 4). The energy resolution is 1.1 keV for 103.6 keV.

Figure 3: Photo of XR-100CdTe detector and PX5.

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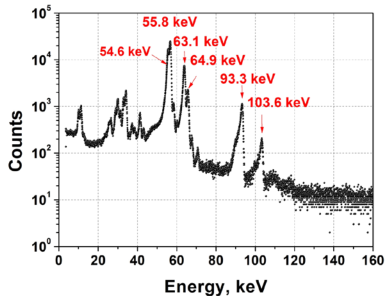

Figure 4: X-ray spectrum from radioactive isotope of ^{180}Ta.

X-ray spectra were measured through a titanium window. A thickness of the window is 70 um. The window was installed near the resonator №3 of U-400M. Measurements were made at the following frequencies of the resonance system: 12.8, 13.317, 15.012, 15.1 and 17.5 MHz. Measurements were made least at three voltages (by pick-up electrodes) at each frequency.

THE FLUKA SIMULATION OF THE X-RAY SPECTRUM

An accurately determining of the maximum energy of X-ray spectrum was difficult because of background radiation from the induced activity of the internal elements of the cyclotron (Fig. 5). The FLUKA simulation of X-ray spectrum was done to accurately determine the maximum energy of X-ray spectrum [3, 4]. An electron beam in the FLUKA model was monoenergetic.

A comparison of the Fluka spectrum with the measured spectrum makes it possible to determine the maximum energy with good accuracy (Fig. 6).

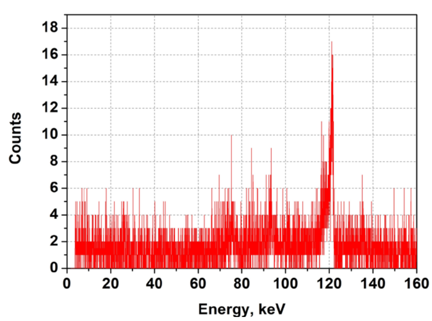

Figure 5: X-ray spectrum of background radiation from the induced activity of the internal elements of the cyclotron.

RESULTS

When measuring the absolute dee voltage, the sensitivity of the dee voltage control system to the frequency of the resonance system was noted. As shown on fig. 7 at the same voltage (55 kV) by pick-up electrodes and at different frequencies, the absolute dee voltages are different.

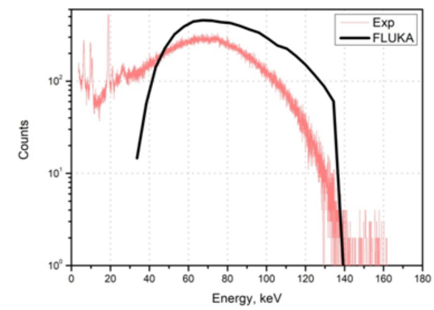

Figure 6: The comparison of the Fluka spectrum ($E_{electrons}$ = 140 keV) with the measured spectrum.

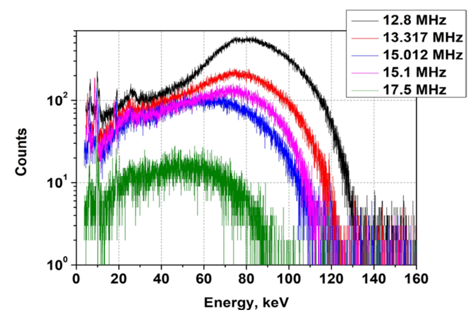

Figure 7: X-ray spectra for different frequencies at the voltage of 55 kV, measured by pick-up electrodes.

The dependence of voltages measured by the pick-up electrodes on the maximum energy of the X-ray spectrum for different frequencies is obtained. The dependence is linear (Fig. 8). Figure 9 shows the dependence of the calibration factor (E_{max}(x-ray)/$U_{pick-up}$) on the frequency of the RF-system. Thus, a universal calibration graph for the control system of dee voltage has been obtained (Fig. 9).

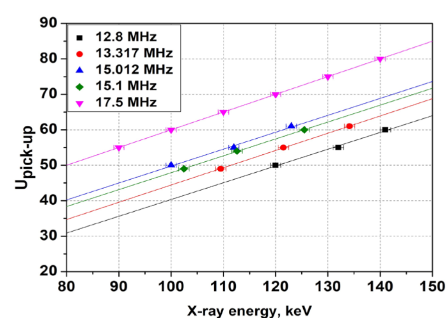

Figure 8: The dependence of voltages measured by the pick-up electrodes on the maximum energy of the X-ray spectrum for different frequencies.

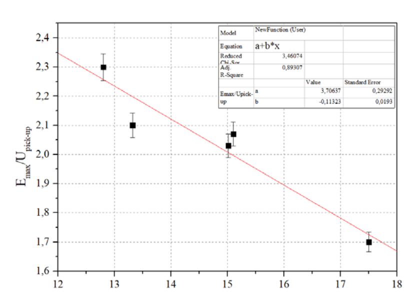

Figure 9: The dependence of the calibration factor (E_{max}(x-ray)/$U_{pick-up}$) on the frequency of the RF-system.

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AN ESTIMATION OF DEE VOLTAGE INFLUENCE ON THE CAPTURE COEFFICIENT

A simulation of the capture in the acceleration of 15N5 + ions (A / Z = 3, fa = 17.5 MHz) was made to estimate the influence of the amplitude of the RF voltage on the dees. The trajectory analysis of the capture and acceleration of ion beams in the central region of the cyclotron was carried out by the Center program. It can be seen from fig. 10 and 11 that at the dee voltage of 85 kV the beam loss on the internal elements of the cyclotron reaches 100%.

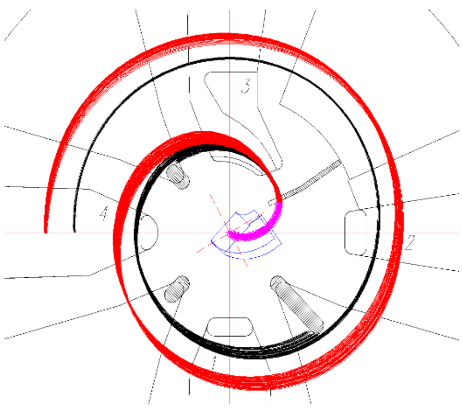

Figure 10: The motion of the injected $_{15}N^{5+}$ ion beam on the first turn at the voltage on dees 85 kV (black) and 120 kV (red).

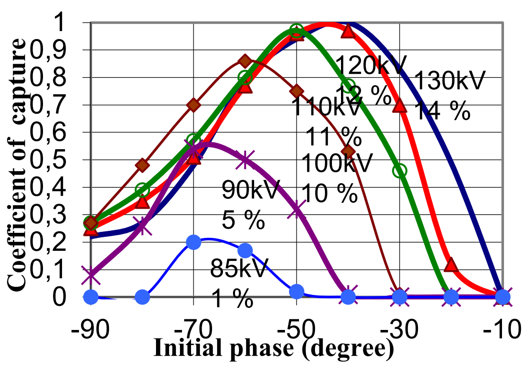

Figure 11: The dependence of the capture coefficient on the acceleration on the initial phase of the beam at different voltages on dees at the first 6 revolutions.

CONCLUSIONS

The absolute dee voltage of the isochronous cyclotron U-400M at FLNR JINR was measured. It was noted that the voltage measurement circuit by pick-up electrodes is sensitive to the frequency of the resonanse system.

The modeling of the X-ray spectrum by the software package FLUKA was carried out to accurately determine the maximum energy of the bremsstrahlung spectrum.

The influence of the absolute dee voltage on the capture factor was estimated by the program Center.

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