MEASUREMENT OF SSC RF CAVITY VOLTAGE WITH X-RAY SPECTRUM METHOD

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Abstract

The principle, method and results of RF cavity voltage measured by X-ray energy spectrum are introduced. X-ray spectrum method is based on the measurement of X-ray generated by field-emitted electrons in RF cavity and measures the absolute RF voltage. Due to no contacts with RF cavity, The RF voltage measured by X-ray spectrum method is accurate and reliable. The RF voltage of Separated Sector Cyclotron of Heavy Ion Research Facility in Lanzhou (HIRFL-SSC) has been calibrated by X-ray spectrum measurement results.

1 INTRODUCTION

HIRFL-SSC consists of two sets of RF resonant cavities. Each cavity is driven by one set of 120 kW RF transmitter. The SSC operation frequency range is 6.5 ~ 14 MHz and the maximum RF voltage is 250 kV.

The RF voltage is an important parameter in accelerator operation. But measuring RF voltage amplitude precisely and accurately is very difficult with common electronics method. Once we used a high impedance and high voltage probe to contact RF cavity and measure RF voltage directly. However, because the probe was contacting with RF cavity, the resonant characteristics of RF cavity was varied and the accuracy of the measured RF voltage was affected greatly. Therefore, using a kind of new method to measure RF voltage becomes important. Fortunately, there is one known method of absolute voltage measurement, the X-ray spectrum method. The upper limit of the spectrum corresponds to the amplitude of the RF cavity voltage. If the spectrum measurement system has been calibrated by using already well-known X-ray lines, the upper end of the spectrum yields the absolute value of the voltage amplitude of RF cavity. Therefore, the voltage amplitude of RF cavity measured by X-ray spectrum method is accurate and reliable.

2 GENERAL PRINCIPLE

Under the condition of no beam injection in the cyclotron, when RF cavity generates dozens of kVs RF voltage between acceleration gap, the field-emitted electrons are accelerated by the RF electric field between RF cavity's electrodes. When the accelerated electrons impact on the electrodes, non-elastic collisions between the electrons and the atoms of electrode's material occur. The energy of accelerated electrons is transferred to the atoms of electrode material. Meanwhile, electromagnetic radiation takes place by the transition of atomic inner electrons. Therefore, a kind of X-ray is generated with continuous energy spectrum. This phenomenon is also called "Bremsstrahlung".

The energies of electrons accelerated by RF electric field are distributed continuously. The maximum electron energy corresponds to the peak value of RF cavity voltage. When the electrons collide with the atoms of electrode's material, the transferred energies to the atoms are from zore to the maximum kinetic energy of the accelerated electrons. Hence, the X-ray spectrums demonstrate continuous energy properties. If we detect the maximum energy of the X-ray spectrum, the RF cavity's peak voltage is thus determined.

Because RF cavity is placed at the magnetic valley between the main magnets in SSC, the magnetic field has no effects on the X-ray spectrum. Additionally, the X-ray spectrum has isotropic distribution. Therefore, the X-ray can be detected through the observer window of the vacuum chamber. Although the intensity of X-ray decreases by $I=I_0e^{-\mu d}$ (μ is absorption coefficient, d is window thickness) when the X-ray passes through the observer window, the energy of X-ray keeps constant.

3 MEASUREMENT METHOD

The X-ray spectrum measurement of SSC RF cavity's voltage is shown in Fig.1.

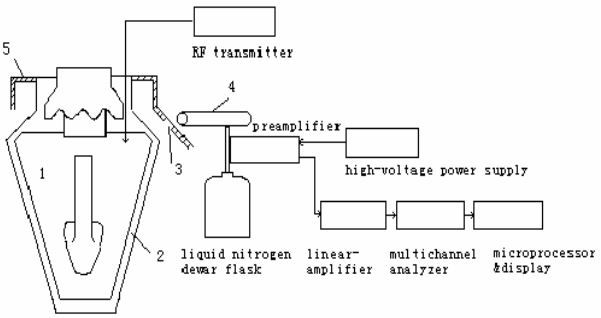

Figure 1: Layout of RF cavity voltage measurement by X-ray spectrum

The plane-type high-purity Ge semiconductor detector GLP-36385 is selected for X-ray spectrum measurement as it has fine energy resolution. The energy measurement range of semiconductor detector GLP-36385 is

3~300keV and it's suitable to measure SSC RF cavity voltage which maximum value is 250kV. This GLP-36385 detector needs a 1500V bias voltage during operation. Its full width at half maximum (FWHM) is about 385eV at 59keV peak energy and 595eV at 122keV. In order to reduce electrical noise in the measurement, the detector GLP-36385 and its pre-amplifier are put into the liquid nitrogen as low temperature as $-196\ ^0$C.

Before measurement, the energy calibration of the detector GLP-36385 was done with ^{133}Ba. The detector channel address was marked at peak energies 30.97keV and 81.0keV of ^{133}Ba. In measurement process, if RF voltage is lower, the accumulation time should be kept longer; conversely, if RF voltage is higher, an obvious energy peak of the X-ray spectrum would appear in less than 90s. Generally speaking, the dead time should be kept under 5% so as to ensure complete counting accumulation and get accurate results.

4 MEASUREMENT RESULTS

In this measurement, SSC RF cavity was excited at three frequency points, 6.8MHz, 10.4MHz and 13.5419MHz and RF voltages were measured by X-ray spectrum method respectively. The measured spectra with different RF voltage are illustrated in Fig. 2 and Fig. 3.

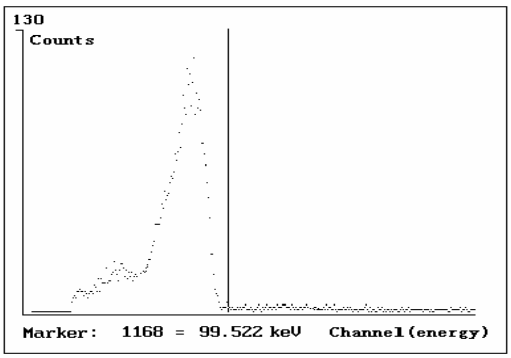

Figure 2: X-ray spectrum corresponding with RF cavity voltage V_D=99kV

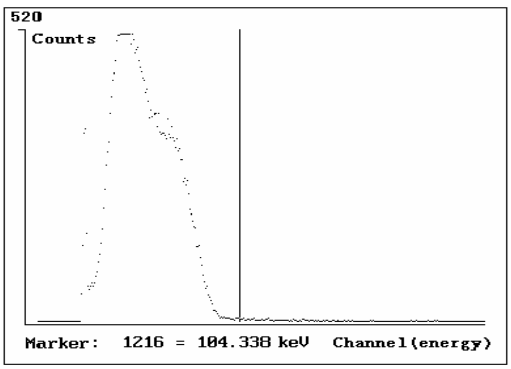

Figure 3: X-ray spectrum corresponding with RF cavity voltage V_D=104kV

Fig.2 shows that when RF cavity voltage is lower, X-ray spectrum energy is also lower and the corresponding background noise is larger. It's necessary to deduct background noise radiation to get X-ray spectrum maximum energy accurately. In Fig.3, the corresponding RF voltage is higher so that X-ray spectrum is comparatively clear.

The measurement results of SSC RF cavity voltage by X-ray spectrum method are listed in Table 1. These parameters are useful to calibrate RF voltage of SSC in HIRFL.

Table 1: SSC RF voltage amplitude measuring results by X-ray spectrum method

Frequency (MHz)	Measuring time (s)	X-ray spectrum measured Vd (kV)
6.8	1017	64
	202	71
10.4	300	92
	150	100
	102	108
	83	116
13.5419	90	87
	90	99
	90	104
	90	126

5 CONCLUSION

- The voltage of SSC RF cavity measured by X-ray spectrum is accurate and reliable due to no variation of RF cavity resonant property induced by measuring probe contacting.
- X-ray generated by RF electric field can be detected at suitable position to measure RF cavity voltage precisely. And this measurement isn't like electronics method influenced greatly by RF frequency.
- According to error analysis, the RF voltage measurement error of X-ray spectrum method is about $\pm$1kV.

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