SNS RFQ VOLTAGE MEASUREMENTS USING X-RAY SPECTROMETER

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Abstract

Absolute measurement of vane voltage is essential to understand RFQ transmission. We used a non-intrusive technique of bremsstrahlung X-ray measurement. Several windows were installed in different locations of the RFQ to allow measurement of the X-ray spectrum. A CdTe spectrometer was used to estimate spectrum cutoff energy that corresponds to the vane voltage. Different device setups are described as well as measurement accuracy and interpretation of experimental data.

INTROUDUCTION

An RFQ is a crucial part of the SNS accelerator. It's performance directly affects beam power on target. The history of RFQ detuning issues [1] increased importance of full understanding and extensive characterization of RFQ parameters. These issues are identified as critical for successful upgrades of the SNS accelerator. The Beam Test Facility (BTF) has been constructed for validation of the new spare RFQ [2]. One of the key parameters is the actual RFQ vane voltage. X-ray spectra measurement is a common technique used to obtain vane voltage independently, not relying on design parameters and magnetic field probes [3, 4]. We first reported the preliminary results of such measurements in 2014 [5].

EXPERIMENTAL SETUP

Theory of Operation

There is always a stream of electrons between RFQ vanes due to the field emission. These emitted electrons are accelerated to the energy corresponding to RFQ voltage and bombard the copper vane. Electrons produce radiation in the form of X-rays with energy spectrum extending up to the energy of an incident electron. Thus measuring the maximum energy of bremsstrahlung X-rays one can obtain the vane voltage.

X-ray Spectrometer

We use an off the shelf X-123 CdTe X-ray spectrometer [6]. Spectroscopy is the main application of this device so one of the main parameters is FWHM (Full Width at Half Maximum). The spectrometer has an internal amplifier that has to be calibrated for a particular energy range. We used Am-241 source for calibration. It has a peak at 69.5 keV that is close enough to maximum expected energy of X-rays – around 80 keV. The FWHM contributes to error of our measurements and is close to 0.8 keV for this energy. The amplifier's settings were optimized to allow binning in 1024-channel MCA with maximum energy 90 keV. The calibration error was estimated to be 0.5 keV at 100 keV for spectrum shown on Fig. 1.

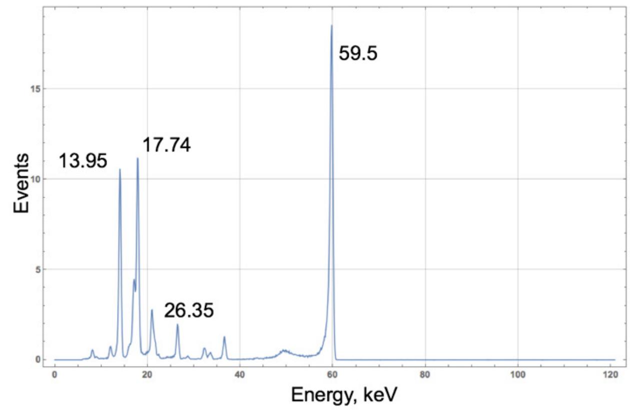

Figure 1: Spectrometer calibration with Am-241 source.

RFQ Ports

Special quartz windows were added to RFQ to allow X-rays reach the spectrometer that is mounted outside of the port looking at the window. The production RFQ that is currently used at the SNS accelerator has four windows. We used one spectrometer and attached it to different

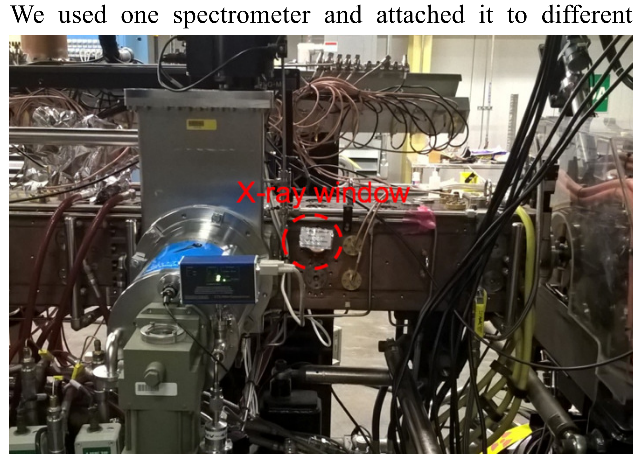

Figure 2: Quartz X-ray window installed in RFQ.

Proof of Principle Measurements

The first set of measurements was done without any shielding enclosure, using vendor calibration and the main goal was to observe correlation of RFQ set point (proportional to vane voltage) and X-rays spectrum. The Fig. 3 shows typical spectrum.

There are different ways of quantifying the cut-off energy [3, 4]. To obtain cut-off energy of the tail we used following procedure: the tail consisting of 0.5% of total events was considered background (shaded grey on Fig. 3), the adjacent 1.5% events were selected and the spectrum was linearized for this part (green shading and red line), intersection of the line with X – axis is called the maximum energy of this distribution.

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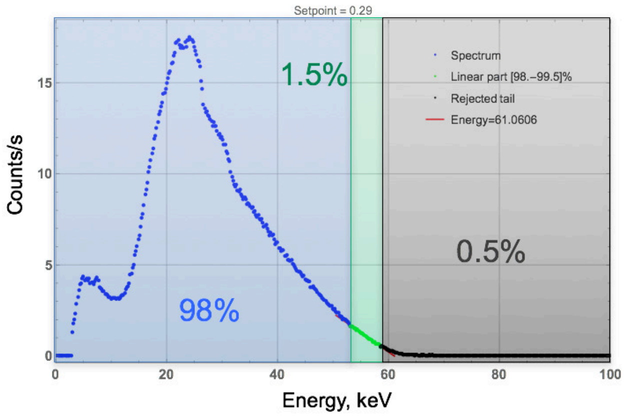

Figure 3: Typical spectrum measured by unshielded spectrometer.

The same procedure was applied to spectra obtained with different RFQ set points and plotted measured energy vs set point value as shown on Fig. 4.

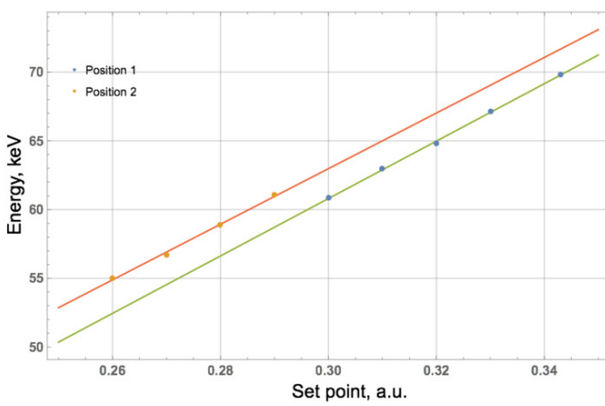

Figure 4: Measured X-ray energy vs RFQ set point taken in two different positions: orange – facing directly the window, green – moved 30 cm away and slightly misaligned.

It's clearly seen that the experimental data is well fitted by a straight line for measurements taken at the same position but there is a significant shift when two positions are compared. Thus, although the technique itself is working, there is no way to measure absolute value of the vane voltage with required accuracy (1-2 keV). Also the resulting energy for production set point appeared to be too low: less than 73 keV, such voltage would not provide RFQ efficiency that we observe in production.

Another issue we encountered is the total amount of radiation at different set points. Since field emission drops significantly with voltage decrease, the counting intensity is different, so we had to move the spectrometer closer for lower field set point. On the other hand, the spectrum is dominated by low energy peak and the spectrometer is saturated when it faces the window directly and the RFQ field is high.

Shielding and Collimation

The SNS front end has many sources of X-rays: the ion source has several high voltage lenses (~ 40 kV) and 65 kV extraction voltage, MEBT RF structures are capable of procuring X-rays with energies up to 100 keV. Since we are interested in X-rays from RFQ only, all other sources are considered background that needs to be filtered out. Since the spectrum by itself is not an objective of the measurement, we are not interested in low energy X-rays coming from RFQ, we have to measure the tail only.

Some filtering is achieved by spatial orientation of the spectrometer. But it appeared to be not enough because levels of radiation from the RFQ itself can vary greatly (10-300 mRem/h) and the radiations levels from rebunchers can vary independently. To alleviate this problem, we came up with a shielding enclosure, shown on Fig. 5, a set of collimators and screens placed in front of the detector's window – Fig. 6.

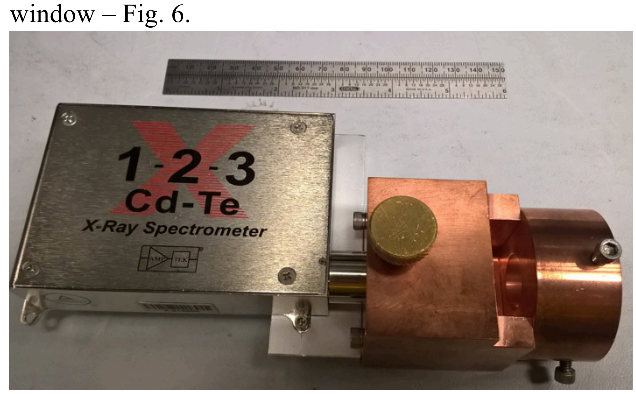

Figure 5: Spectrometer inside copper enclosure.

The outer shielding decreases input from background sources, the collimation makes sure that the source is actually vane's tip, and screen removes low energy part of the spectrum.

Figure 6: Set of collimators and screens.

Data Acquisition

We used the standard AmptekDpp [6] software that came with the spectrometer. It has an extensive set of parameters, that allow adjusting for different MCA thresholds, amplification settings and pulse shaping. We started with a standard spectroscopic configuration and then tailored them for high energy measurements: increased fast threshold to maximum. Since these settings are somewhat extreme we made sure that the peaks of calibration spectrum shown at Fig.1 is still reproducible with these settings.

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RESULTS FOR SNS PRODUCTION RFQ

Considered the issues mentioned above we tested different collimation and shielding configurations and settled down on having a 2 mm pin hole behind 3 mm of copper shield. The enclosure itself has at least 1.5 cm of copper shielding around the detector, see Fig. 5. We also performed in house calibration with a radioactive source. Such modifications significantly changed the shape of observed spectra and absolute value of cut off energy Fig. 7 shows spectra measured at different ports. The spectrometer was attached directly to ports.

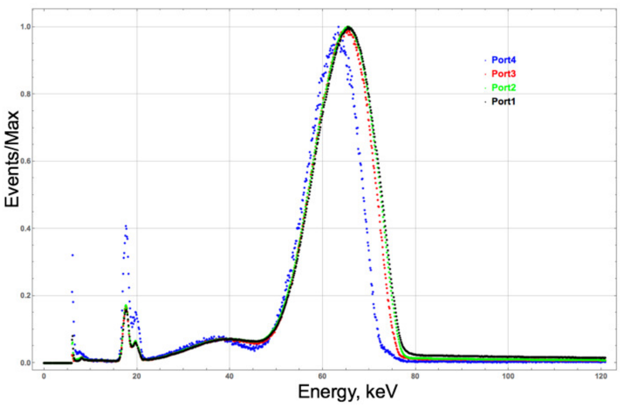

Figure 7: X-ray spectra at different ports, normalized over peak maximum.

As expected the low energy part was suppressed by the shield in front of the collimator. The port 4 (blue plot on Fig.7, the most downstream location) is significantly different from the other three ports. It's important to mention that its main high energy peak is shifted, while the bimodal peak below 20 keV seems to be in the same place (due to MCA nature of measurement the relative error is higher for lower energies, since the histogram bin width is constant). Also the ratio of main peak's maximum to low energy peak's maximum is constant for Ports 1-3, but is different for Port 4. And the most important difference demonstrates itself in the tail region. The "end" of the distribution comes to the same point, although the peaks are really different. Unfortunately applying the linearization technique described above gives different values of energy: 72.3 keV for port 4 and 75.9 keV for other ports, which is expected since the shape is different and the technique works fine for similar shapes. The absolute values measured for ports 1-3 are within 76-77 keV and are much closer to expected values.

CONCLUSION

We performed an extensive set of measurements trying to quantify the edge of X-ray spectrum caused by field emission in RFQ vanes. We successfully proved that the described linearization method works well for spectra with similar shape. A special collimated enclosure was designed and built to filter out X-rays from irrelevant sources. We were able to estimate the vane voltage of SNS RFQ within 2.5 keV (76 keV for field set point 0.323).

Spectra were measured for different ports and show similarity in shape for ports 1-3 and is different for port 4.

Future Plans

The RFQ parameters are known to change over time due to different reasons, so it will be beneficial to have several spectrometers to measure different ports simultaneously. The set of collimators allows to measure background with no pin-hole and subtract it from the measurement with a pin-hole. Such approach is not straightforward because of the pulse pile-up effects. Pile-up affects the artificial tail of the spectrum and is dependent on radiation intensity. Bringing down total number of counts per second (to avoid pile up) will require a significant time of measurement, so there should be a carefully designed trade off.

We also plan to have similar measurements for the spare RFQ after it is commissioned. There will be less background radiation and we will have more opportunities for measuring at different field settings.

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