AN INTERNAL TIMING PROBE FOR USE IN THE MSU K1200 CYCLOTRON*

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Abstract

A probe was installed in the K1200 to measure the internal beam time structure as a function of radius. Using the fast rise times of a Si detector, which was specially cut to extend the active area to within 150 μm of the detector edge, the time of arrival of the heavy ions on the detector is measured with respect to the accelerating RF voltage. Limited to count rates of several kHz, use of the detector requires attenuation of the injected beam, and permits studies of single particle beam dynamics.

I. THE TIMING DETECTOR

The development and use of a Si PIN diode as an external timing detector to measure the RF time spectra of the MSU K1200 extracted ion beam was previously reported[1]. The success of the external detector was an initial step in developing an internal timing detector for the K1200 cyclotron. The basic idea takes advantage of the large signals produced when heavy ions are incident upon a Si detector. This is possible in the K1200, because the injection beam line has attenuators which can reduce the injected beam current by 6 orders of magnitude[2], which keeps the detector count rate manageable, and increases the life of the Si detector. It is useful in the K1200, because beam intensities of highly charged heavy ions produced in the ECR's are too low for the longitudinal space charge force to alter the beam.

Table I
Detector Characteristics Prior to Cutting.

Device	Bias Voltage	Active Current	Guard Current
Uncut	40 V	65 pA	650 pA
Cut outside inner guard ring	50 V	35 pA	509 pA
Cut inside inner guard ring	50 V	65 pA	560 pA

The small turn separation inherent in a compact, 5 T cyclotron, approximately .6 - .7 mm in the K1200 near extraction, presents a significant challenge in using a Si detector to collect the beam, because the guard rings that shape the electric field inside the detector, create a large dead area around the edge. The Senter for IndustriForskning, in Norway, met this challenge by providing three detectors, one which was cut outside the innermost guard ring, one which was cut inside the innermost guard ring, and a reference detector. The increase in leakage current due to mounting and cutting these detectors is presented in Tables 1 & 2[3]. The detectors were bench tested with an alpha source. The fast signal obtained with an LBL Time Pick-Off from the detector with the inside cut did change, adding a shoulder to the falling edge, but the rise times were unaffected, all at 5 ns. The dead areas of these detectors were estimated to be between .15 – .19 mm for the detector with the outside cut, and between .01 – .10 mm on the detector with the inside cut[3].

Table II
Detector Characteristics after Cutting and Mounting.

Device	Depletion Voltage	Active Current	Guard Current
Uncut	40 V	1.3 nA	2.4 nA
Cut outside inner guard ring	35 V	38 pA	18 μA
Cut inside inner guard ring	40 V	4.0 μA	4.3 μA

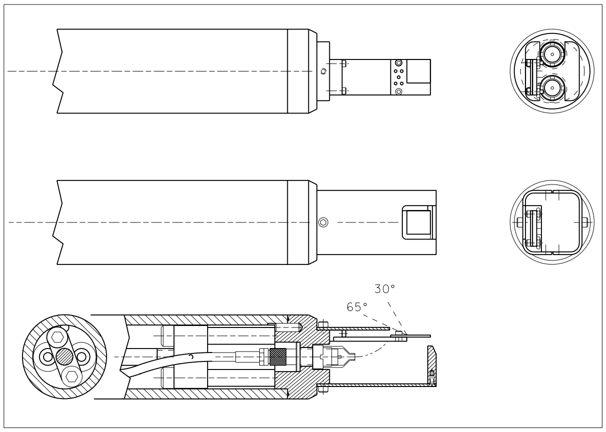

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Figure. 1. K1200 Timing Probe Head. The detector mount, and RF shield are depicted above. Th cut away shows vacuum feed throughs, and beam clearance of the RF shield.

The probe head, depicted in Figure 1, inserts the detector into the beam. The cut edge of the detector extends out from the edge of the probe. A copper RF shield around the detector, has a notch cut in it which allows the ions to strike the detector without first hitting the shield. The bias voltage is supplied, and output signal extracted through two vacuum feed throughs. The probe is then inserted into the cyclotron in the hill, which doubles as a dummy dee.

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II. USING A Si DETECTOR INSIDE A CYCLOTRON

There are several concerns when using the detector inside the cyclotron. First, the corner of the detector is pushed into the beam, allowing the ions to traverse only a small part of the detectors active area. To simulate the response of the detector, the energy loss profile for ions incident on the detector was calculated with the program ELOSS[4]. A simple model of the detector, developed by Spieler[5], was used to simulate the charge collection of the detector. The output signal from the program simulates the output of the detector reasonably well. This is passed through a simulation of a constant fraction discriminator. The final result, shows a variation of 40 to 50 ps between the measured time of arrival of ions which hit the edge, and those which hit the center of the detector.

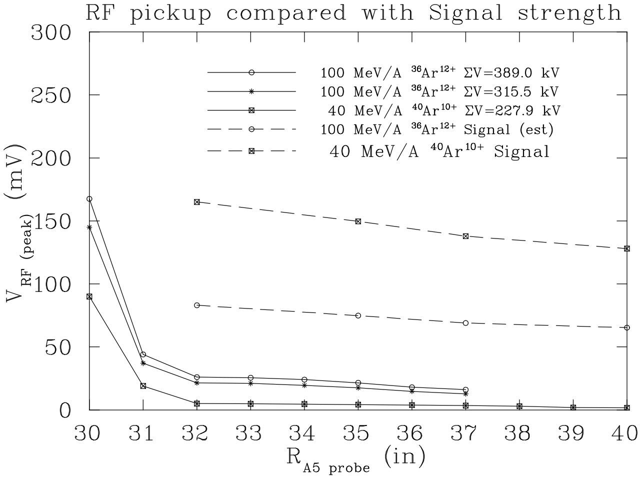

Figure. 2. Relative Strengths of Beam Signal and RF Pickup. The measured RF pickup of the detector from the dees is relatively constant until the probe begins to approach the accelerating gap. The strength of the beam signal is also displayed as a reference.

Second, the notch in the RF shield allows the detector, as a capacitor, to pick up a signal from the accelerating electric field. Since the hills spiral, due to the spiral in the magnetic field, as the detector travels deeper into the cyclotron it begins to approach an accelerating gap. Figure 2 shows the measured strength of the RF pickup, compared to the signal strength of Ar ions as a function of detector radius. It is clear that inside of 32 in the detector won't see any signal. To calculate the effect of the RF pickup on the measurements, the pickup sine wave was added to the detector simulation. Care was taken so that beam followed the calculated phase curve of the cyclotron, and that the phase of the sine wave was correct for the time of arrival of the ion on the probe. The measured time of arrival has a radially dependant shift. The RF stop signal used in the time measurement is relative, and not absolute, so the net shift is unimportant, but radial differences are important. The radial difference varies by 40 ps when the pickup is 6% of the beam signal, but when the difference is 30%, the measured beam time can vary by 800 ps. Also, since the beam has a time spread, a 30% RF pickup will widen the measured beam time by up to 200 ps for $\Delta\phi = 10^\circ$ RF, and 600 ps for $\Delta\phi = 40^\circ$ RF.

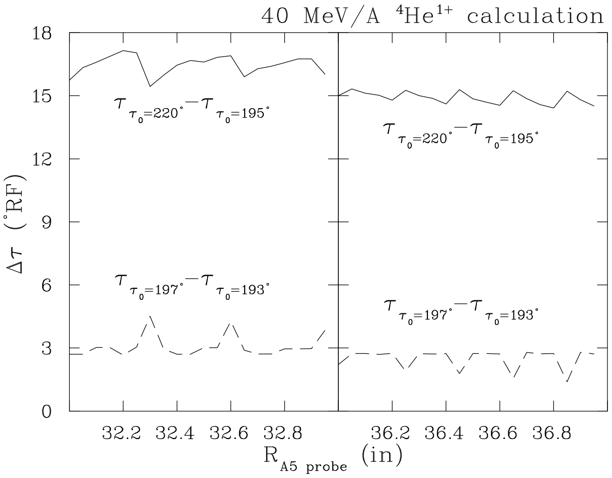

Figure. 3. Calculated Variation in Measured Time Widths Due to Precession. Precession will cause the measured time width of the beam to vary periodically as a function of the radius at which it is measured. The starting time of 220° RF is centered.

The detector collects one beam pulse over many turns. At 32 in, it takes about 20 turns, and at 40 in, it takes 35 turns. This allows multi-turn effects to influence the measurement. The phase slip per turn is small so, except near extraction, this will have little effect. One measurement though show that for extreme conditions this slip is significant. An analog beam that was about to fall out of resonance grew fourfold in width before it was lost. Also, as the energy gain per turn became so small that only the radial precession could clear the detector dead area, the beam spread into several small peaks. Radial precession of off centered beams, though, will have an effect. Figure 3 shows the calculated effect of precession at two different radii for a beam 4° wide and one 25° wide in RF starting times. The phase compression is from the central region, and is real, but the variation in calculated width shows that precession can cause an error as large as 2° RF. The sign of the error corresponds to the slope of the phase curve. This is true for any method of measuring phase widths internally. The solution is to take a measurement in an area where one expects the phase curve to have zero slope, and to move the detector a small amount and repeat the measurement.

III. INTERNAL BEAM TIME MEASUREMENTS

Both of the cut detectors were successfully used as timing detectors in the K1200 cyclotron, performing equally well. Figures 4 & 5 show the versatility of these detectors. In Figure 4, the detector measured the outer portion of the phase curve. Spectra were taken every inch, from 32 to 40 inches. The centroids were calculated, and corrected for travel time of the beam from the dee center to the probe. These were then fixed in absolute phase by a Smith–Garren frequency swinging phase measurement at the three innermost data points. (This technique, which is extremely slow, does not work in the K1200 at radii greater than 34 inches, since the phase diagram has a maxima there.) For comparison, a

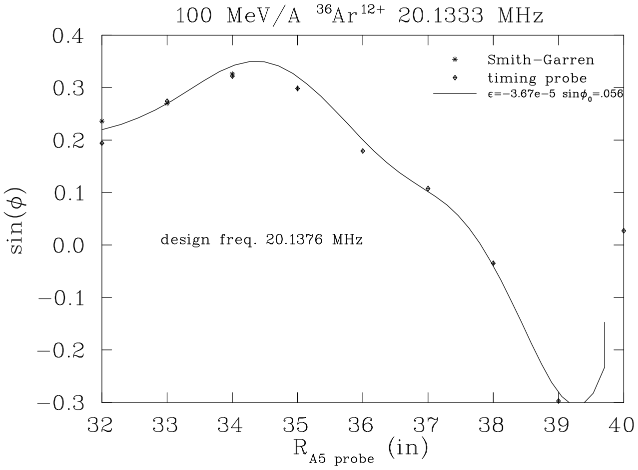

Figure. 4. Phase Curve Measured with the Internal Timing Probe. The phase curve was measured using the internal detector. The timing probe can only measure relative changes, so one point was fixed using a Smith–Garren measurement. The calculated phase curve was then fit to the data, varying frequency and starting time, demonstrating the accuracy of the magnetic field calculations.

phase curve from a calculated magnetic field was fit to the data, with extremely good agreement.

Figure 5 shows several beam time spectra which were taken with the internal probe. The left most, and center spectra show the results of inserting one of the phase slits, while the right most spectra show the results of both slits inserted into the beam. The scale is in channels, at 50 ps per channel. The bottom row was done without the buncher, and the top row was used to emphasize the intensity of the main peak, relative to the other peaks. These spectra show the detectors' ability to resolve fine sub-nanosecond structures, approx 250 ps wide, as well as its usefulness in tuning the phase slits.

In summary, a Si detector was implemented as an internal beam timing detector in the K1200 cyclotron. It proved to be useful in measuring phase curves, and tuning the phase slits, as well as demonstrating a 250 ps resolution. It is ready for use in studying the time aspects of single particle beam dynamics.

References

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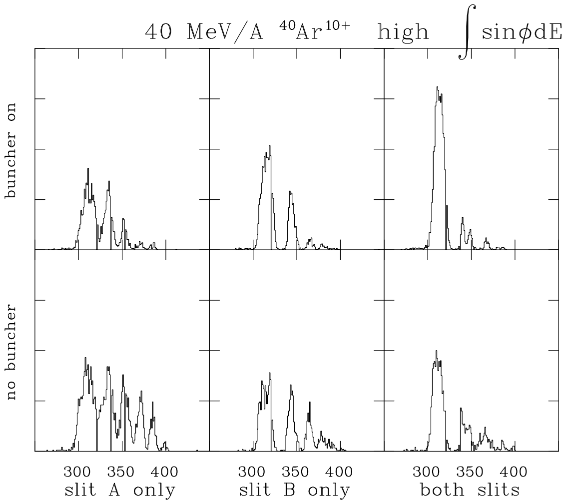

Figure. 5. Time Spectra Measured with the Internal Timing Probe. Time spectra measuring the effects of the phase slits, which are really posts inserted into the beam, and the buncher. One phase slit makes multiple cuts in the beam, and the two together with the buncher are used to select and enhance one peak for transmission, while cutting the others. Each channel is 50 ps. Note the small peak widths, one of which is only five channels wide FWHM.