External Beam Phase Width Measurements at the JAERI AVF Cyclotron

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Abstract

Time structure of proton beams extracted from the JAERI AVF cyclotron has been measured with a set of plastic scintillators. A narrow peak of 3° FWHM in RF phase width was observed for a 10 MeV proton beam with the beam intensity reduced. With 70 MeV proton beams, phase widths of 7.4° and 32° FWHM have been found for beams with and without internal phase cutting, respectively. Preliminary simulations of internal and external beam phase distributions have been carried out by orbit calculation. The calculated external phase widths are consistent with the measured ones.

1 INTRODUCTION

The K110 JAERI AVF cyclotron[1] is a multi-particle cyclotron providing ion beams at energies of 5 to 90 MeV for protons and 2.5 × M to 110 × Q^2/M MeV for heavy ions. Harmonic numbers of h=1, 2 and 3 are available for covering a wide range of energies. A constant orbit method is adopted to determine the dee voltage. The total turn number of the beams reaches 550 for h=1, 265 for h=2 and 210 for h=3. RF phase of the internal beam is quite sensitive to field deviations from isochronism because of the large number of turns. The initial phase width of the beam can be defined with two sets of slits[2] cutting the beam radially on the first turn. The internal beam produced without phase cutting spreads radially by a few centimeters before extraction. Extraction efficiency is limited due to multi-turn extraction, and expected to be improved by confining the phase width. We have measured intensity distributions vs. phase of the external beams in order to investigate the correlation between the beam phase width and the positions of the phase cutting slits.

The external beam phase depends on the internal one, but also on energy and on transmission in the extraction region. Time structure of the external beam transported over a long distance is changed if the energy spread is not negligibly small. If the beam phase is strongly correlated to the spatial position of the particles, the phase width is reduced due to beam cutting at devices in the extraction region and along the beam transport line. The internal beam phase distribution has been simulated with an orbit calculation code, since no detector for measuring time structure is installed in the cyclotron. We have also investigated the effects of energy spread and of the spatial cutting in the extraction region onto the external beam phase distribution.

2 MEASUREMENT APPARATUS

The external beam phase has been measured with a set of plastic scintillators, by detecting protons directly, or by detecting protons scattered elastically from a 0.03 mm thick titanium foil. Schematic layouts of the measuring systems are shown in Fig. 1. The plastic scintillators are installed at the end of a beam line, at 41.2 m from the cyclotron. The telescope-type plastic scintillators are used to distinguish the protons from other particles produced at the foil. Events of directly detected or of elastically scattered protons are selected on a ΔE-E correlation spectrum.

The beam intensity is reduced using up to three attenuators to allow for direct proton detection. The attenuators are installed at three different locations in the beamline for the injection into the cyclotron. Each attenuator is composed of two or three stainless steel plates, each having a lot of small holes arranged in a regular pattern.

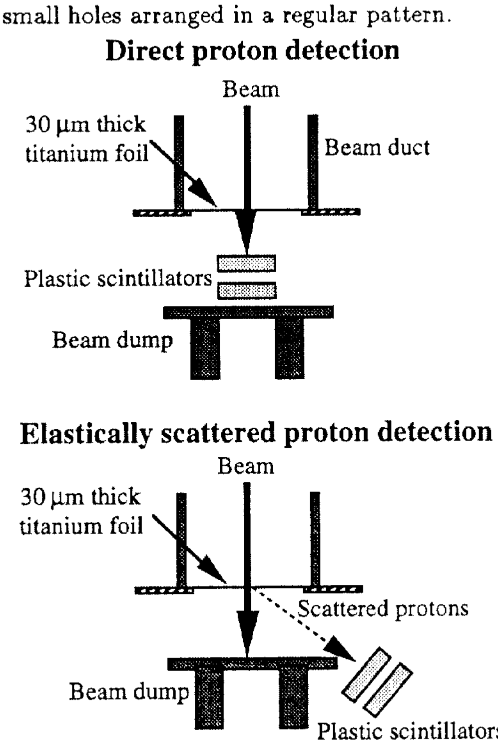

Figure 1: Schematic layouts of the measuring systems for the direct proton and elastically scattered proton detection.

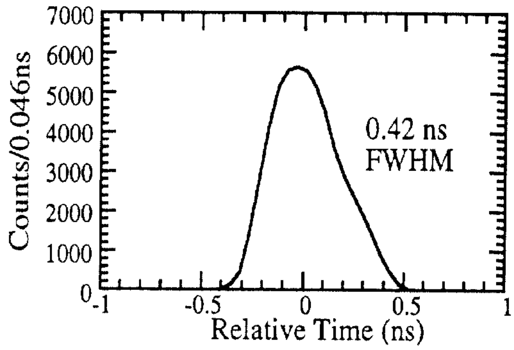

Figure 2: Time resolution of the plastic scintillators measured with a 70 MeV proton beam. The peak width of 0.41 ns FWHM gives a time resolution of 0.12 ns.

A time spectrum is obtained by measuring a time lag between signals coming from the detector and the RF reference. Data are collected with a CAMAC interface and sent to a personal computer. Correlating the signals of a pair of scintillators, the time resolution has been measured with a 70 MeV proton beam. This result of the measurement is shown in Fig. 2. It is 0.41 ns FWHM, which corresponds to an individual resolution of σ=0.12 ns. This resolution is sufficient for measuring the beam intensity distribution vs. phase.

3 EXTERNAL BEAM PHASE DISTRIBUTION

3.1 10 MeV Proton Beam

The external beam phase of the 10 MeV protons was measured by detecting the protons directly. The initial beam intensity of around 10 nA was lowered by a factor of 10^6 with the attenuators. Figure 3 shows the beam phase distributions for the two cases, with and without phase defining slits. Without phase slits the beam intensity distribution is split into several components. Full width of the beam phase reaches 75°, which includes the broadening effect due to the energy spread. The phase distribution for the beam with phase cutting shows two components separated by 18°, which are narrow peaks of 2.2° and 3.4° FWHM phase width. These narrow partial peaks are probably caused by excessive cutting of the injected beam with the attenuators. After attenuation, only selected parts of the beam phase space at injection remain populated.

3.2 70 MeV Proton Beam

For the 70 MeV proton beam, the beam phase measurement has been carried out by detecting elastically scattered protons. For detecting the scattered protons with internal phase cutting the attenuation factor was only 10^{-1} while it was 10^{-5} without phase cutting. Phase distributions for the beams with and without phase cutting are shown in Fig. 4. For analysis of the full beam, we assumed the phase spectrum to be composed of two peaks. The spectrum was

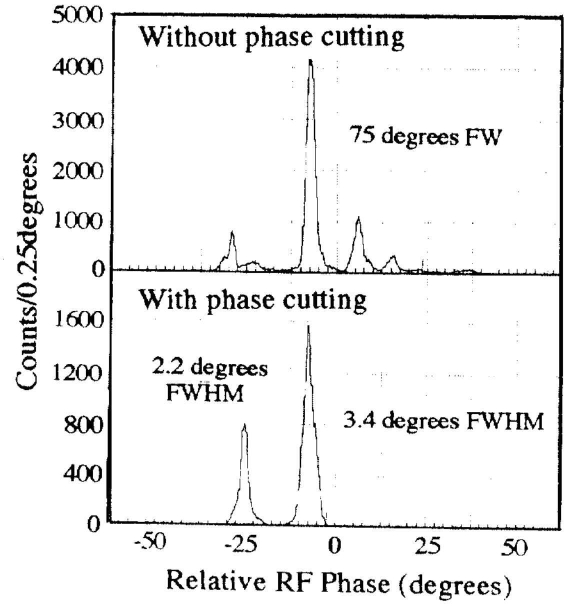

Figure 3: External beam phase distributions for the 10 MeV protons accelerated using the second harmonic at a RF frequency of 14.97 MHz. The initial beam intensity was reduced with the attenuators. Phases are relative, and zeros are not absolute.

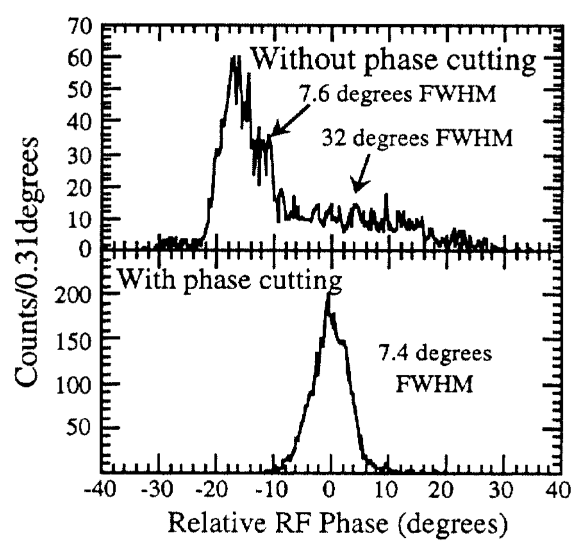

Figure 4: External beam phase distributions for the 70 MeV protons accelerated using the first harmonic at a RF frequency of 18.919 MHz. Phases are relative, and zeros are not absolute.

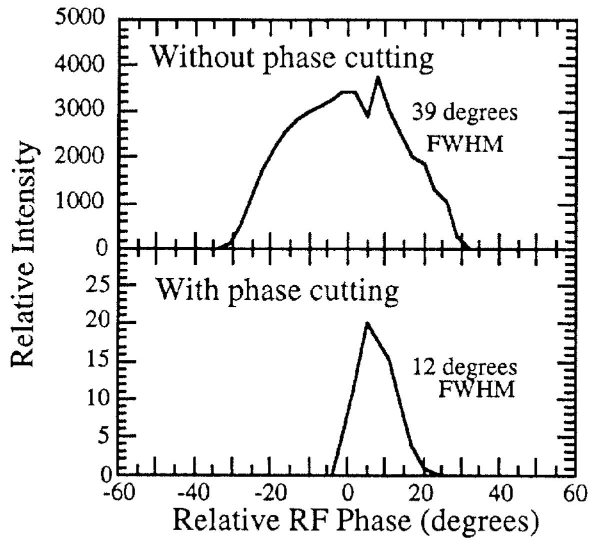

Figure 5: Calculated internal beam phase distributions for the 70 MeV protons with and without phase cutting. Peak widths were evaluated using a Gaussian function.

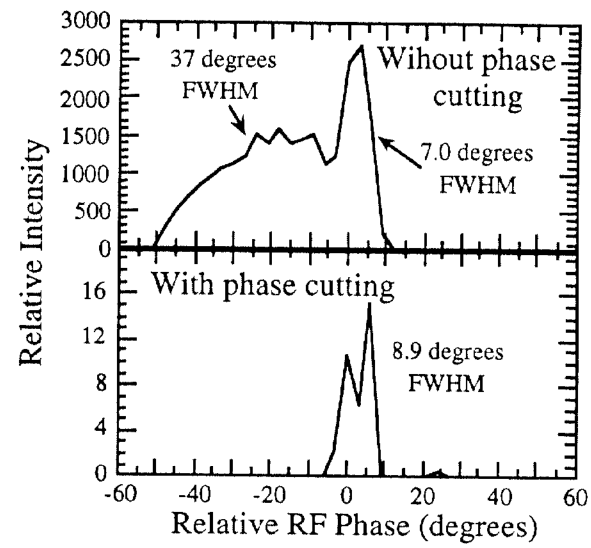

Figure 6: Calculated external beam phase distributions for the 70 MeV protons with and without phase cutting. The spectrum for the beam without phase cutting was fitted using two independent Gaussian functions.

fitted by using two independent Gaussian functions. Phase widths of the two components have been found to be 7.6° and 32° FWHM. The phase width of the beam with phase cutting has been evaluated to be 7.4° FWHM.

4 CALCULATION OF THE INTERNAL AND EXTERNAL BEAM PHASE

The cases of the 70 MeV protons have been simulated using an orbit calculation program. The acceleration parameters that were active at the measurements have also been applied to the calculation. Initial emittance of the beam at the exit of the inflector electrode was assumed to be 300π mm·mrad, which is larger than the acceptance of the inflector. The initial radial phase space area of 9.6 mm × 800 mrad has been covered with simulated particles lying on a grid with spacing of 0.6 mm and 50 mrad. The simulated particles were given an intensity weight function such that the beam would obtain a Gaussian distribution with 300π mm·mrad for the 80% emittance. This weight function is assumed to remain valid through acceleration and extraction.

Preliminary results of the simulation are shown in Fig. 5 and Fig. 6. Internal beam phase widths were calculated to be around 12° and 39° FWHM for the beams with and without phase cutting, respectively. Initial phase acceptance is considerably large. The internal beam has been found to have an energy spread of 2.4% due to precession and to large phase acceptance. The protons of the low energy tail are stopped in the extraction region. For the energy spread of the external beam a value of 1.3% has been calculated. This is not negligible for a long flight path of 41.2 m, but neither does it strongly disturb the measurements. The phase widths of the two main peaks in the external beams without phase cutting are calculated to be 7.0° and 37° FWHM. For the beam with the same phase cutting as in the measurement the phase width is estimated to be 8.9° FWHM. Although detailed time structure of the external beam shows differences between measurement and simulation, the calculated phase widths are consistent.

5 CONCLUSION

The beam properties for the 10 and 70 MeV proton beams have been investigated measuring the intensity distribution vs. phase of the external beams. A narrow phase width of 3° FWHM could be measured for the 10 MeV protons. External beam phase width of the 70 MeV protons has been found to be reduced to 7.4° with phase defining slits. Internal and external beam phase distributions have been simulated with an orbit calculation program. The preliminary results of the simulations are consistent to the measured ones. The effects of energy spread and of cutting in the extraction region onto the external beam phase distribution are not negligible.

6 REFERENCES

[1] K. Arakawa, et al., "Construction and First Year's Operation of the JAERI AVF Cyclotron", in Proc. of the 13th Int. Conf. on Cyclotrons and their Applications, Vancouver, Canada, July 1992, pp. 119-122.

[2] M. Fukuda, et al., "Beam Studies of Injection to Extraction System for JAERI AVF Cyclotron", in Proc. of the 13th Int. Conf. on Cyclotrons and their Applications, Vancouver, Canada, July 1992, pp. 423-426.