A BEAM ENERGY MEASUREMENT SYSTEM AT NIRS-930 CYCLOTRON

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Abstract

A beam energy measurement system employing a set of capacitive probes has been developed at NIRS-930 cyclotron. Principle of the measurement is applying a modified-TOF method, so that the two proves are installed at one of the straight section in the beam transport line. Usually they are separated about 5.8 m, which is equivalent to the almost final path length of the beam extracted in the cyclotron. In the measurement, two beam signals are superimposed by adjusting a position of the downstream-probe along the beam direction with watching an oscilloscope screen roughly. In order to determine the beam energy accurately the signals are processed by MCA with suitable electric module.

INTRODUCTION

The NIRS-930 cyclotron[1] having K=110 consists of four sectors and two Dees (86 deg.) connected to moving panel type of rf-cavities. The frequency-range of 10.7-21 MHz covers 1st and 2nd harmonic in the acceleration modes. The stable beams of proton with energy up to 70 MeV, deuteron, ^{3}He, alpha and few kind of heavy ions are sufficiently delivered with the extraction efficiencies of 50 ~ 85 % and maximum beam current of up to 30 μA. The cyclotron has been used [2] mainly for production of the short-lived radio-nuclides, research of bio-physics for heavy ion cancer therapy in HIMAC[3], development of particle detectors for space application and so on.

Recently, it has been required to know an absolute beam energy just providing at that time for the experiment. One of the case in the RI production, the experiment is mainly development of new short-lived radio-nuclides, so a excitation-function in the nuclear reaction has to be measured, where the value of the absolute beam energy is required as the important parameter.

Many kind of methods have been developed to measure a beam energy extracted from a cyclotron, especially TOF method has been used widely to measure the energy of neutron and charged particle beam. In this measurement system, two particle detector are used in an exactly know distance, and measure a flight time of the beam bunch. Using the similar equipments to the TOF, a new method for measuring the mean energy on cyclotron beam has been developed [4], which determine the beam energy by measurement of the special separation between the beam-bunchs extracted from cyclotron.

In our present study is applying this method to the cyclotron in order to measure the absolute beam energy exactly. In the following sections described a review of the method, system composition, and result of performance are described.

METHOD

The beam energy: T extracted from a cyclotron is given with the relativistic expression by

$$T = E_0\left(\frac{1}{\sqrt{1-\beta^2}}-1\right) \quad (1),$$

where E_0 and β are the rest-mass energy and the normalized velocity of the particle, respectively. When the particle is accelerated by radio-frequency of f_{RF} with a harmonic-number of h, the function of β is represented by

$$\beta = \frac{f_{\mathrm{RF}}}{c}\cdot\frac{2\pi\cdot R_{\mathrm{EXT}}}{h} \quad (2).$$

In a fundamental acceleration mode (h =1), the parameter of $2\pi\cdot R_{\mathrm{EXT}}$ means the final circumference of the extracted beam, in other word this length is same as a spatial separation L_{B} of the beam bunch in a transport line corresponding to the mean radius of R_{EXT}. Therefore, absolute energy of the extracted beam is calculable by measuring the length of L_{B}. In order to determine the spatial separation for the bunch- to- bunch, suitable beam pick-up monitor system is used, and set into the transport line. For the case of other harmonic mode of h =2, it ca be used in the same way as the h =1, because the extraction radius (R_{EXT}) of the beam is the almost same as h =1. The relation of the spatial distance for the beam bunch in the both modes of h =1 and h =2 is illustrated in Fig.1.

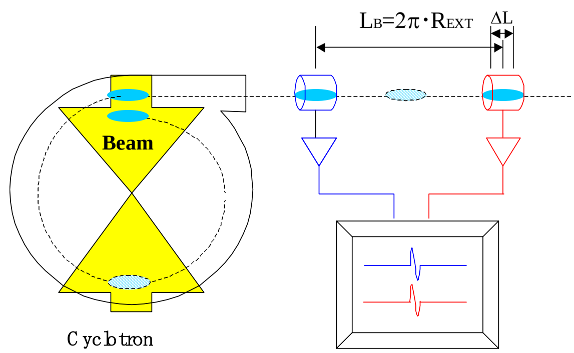

Fig.1. Layout of beam bunch distribution on transport line for acceleration mode of h = 1 and h = 2.

SYSTEM

The beam energy measurement apparatus is consists of two beam pick-up probes, high frequency amplifiers, high-resolution oscilloscope, signal processing electronics, and data acquisition system.

A capacitive type of the pick-up probe formed by a cylindrical shape having 20 pF with longitudinally length of 30 mm and inner-diameter of 56 mm. The two proves are installed one of the straight section in the beam transport line. Usually they are separated about 5.77 m, which is equivalent to the almost final circumference of the beam extracted in the cyclotron. Fig.2 shows a schematic drawing of the arrangement of the probes of No.1 and No.2 in the cyclotron facility. The probe No.2 for downstream-probe can be changed its position along with the beam direction by ± 90 mm, which covered deviation of the extracted radius: ΔR_{EXT} for about ± 14 mm.

The pick-up electrode detects an electrostatic induction produced by a longitudinal distributed beam-charge, and the signal is amplified by two stages of fast and wide band amplifiers having the impedance of 50 Ω.

In the measurement, the two beam signals from the pick-up probes are superimposed by adjusting a position of the downstream-probe along the beam direction with watching an oscilloscope screen. To avoid a systematic error as a time difference owing to the length of the transmission cables from the each pick-up probes was carefully investigated, resulting it was less than 80 pico-second take into account.

In order to determine the beam energy more accurately Multi-Channel-Analyzer (MCA) has been applied for the signals process and tested with suitable electric module. In the MCA system TAC of the standard NIM electric module is used in order to measure the time difference between the two signals from the pick-up probes. Hence the bipolar signals from the probe are thin out its duty by ~1/100 pass through a high frequency analog-gate module which is not the NIM-module, and detected its zero-crossing timing by using crossover timing SCA in the pre-station of the MCA. A block diagram of the readout system is shown in Fig.3. In this system using the MCA, a time resolution of about 50 pico-second / channel i.e. the order of 1×10^{-3} of the measurement resolution will be expected.

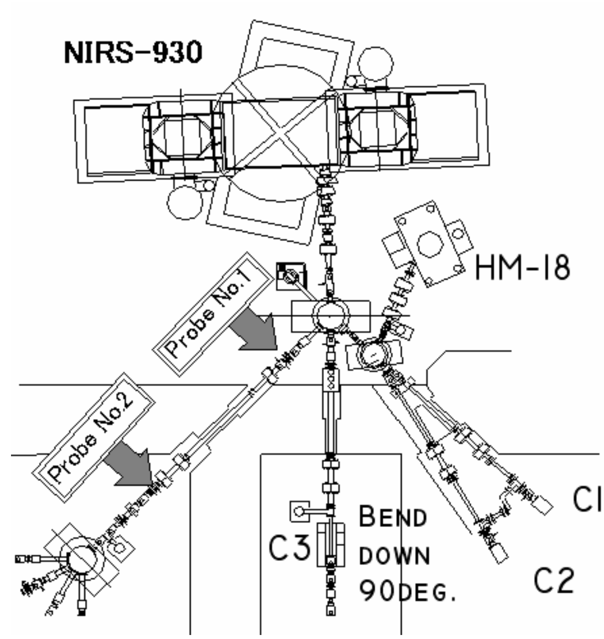

Fig.2. Schematic drawing for beam pick-up probe arrangement in transport line.

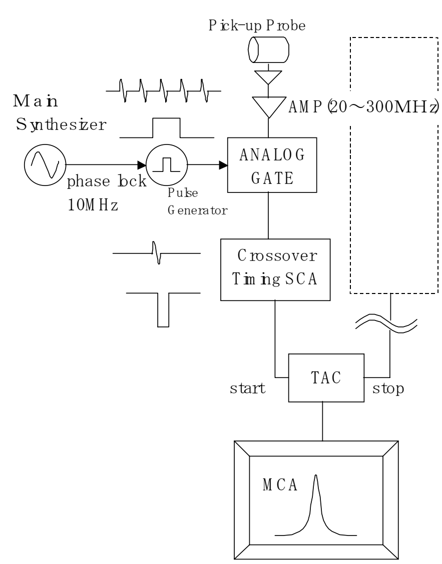

Fig.3. Block diagram of signal processing electronics for MCA. A set of two signals from amplifiers are thin out by analog-gate module, see in text.

MEASUREMENT

The absolute beam energy is determined to measure the spatial distance between the beam bunches extracted from the cyclotron as described in section 2. The distance of L_B is obtained by measure a deviation from a reference distance of L_0 = 5771 mm, which is regarded as a length of mean circumference calculated on a hypothetical extraction radius in the cyclotron, and that is as same as the distance between two pick-up probes on the initially setting position. In the measurement, two beam signals are superimposed by adjusting the position of the Probe No.2 along with the beam direction by an on-line control. So that the small deviation of ΔL from the reference distance should be measured, then the L_B is found by $L_B = L_0 \pm \Delta L$, where the position setting and read-out accuracy less than 0.1 mm.

Several beam energy has been measured for proton, 3He2+, and α beams extracted from the cyclotron. Fig.4 shows a typical beam signal after 50 m long of transmission cables for α-beam with the energy of 40 MeV and current of 0.5 μA. In Table 1 the measurement results are listed up as contrasted with septum position and nominal energy, where the nominal energy means the energy-value of traditionally used which calculated by the relation of Eqs (1) and (2) with hypothetical extraction radius. In comparison with the nominal and the measurement energy, the difference is mainly caused by the difference of setting position for the septum in the operation, because the septum position is directory influence on the extracted beam energy as can be seen in the Table 1. In the cyclotron operation, however, if high beam intensity and/or high extraction efficiency was required for the beam extraction, it had been taken first priority, then the position has been adjusted for the tuning in usually.

The absolute beam energy extracted from the cyclotron is also varied by a bump-field produced by the harmonic-coil in the excitation region, because its act on the beam orbit to take a precession motion.

As to for a reliability of the system for example, a deviation of the measurements has been less than ±0.5 % in the beam intensity range of higher than 0.3 μA .

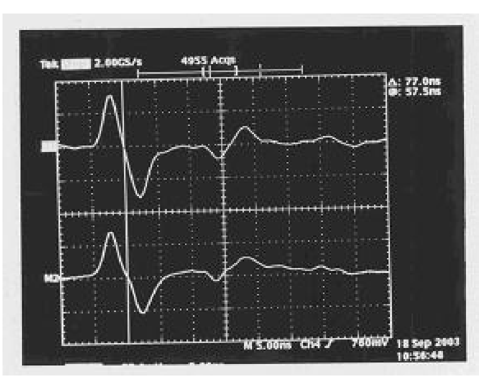

Fig.4. Typical two signals from Probe No.1(upper) and No.2 (lower) for 40 MeV α-beam at intensity of 0.5 μA.

Table 1. Measured beam energy

Beam type	Nominal Energy [MeV]	Measured		operating parameter		
		Energy [MeV]	R_{ext} [cm]	Septum position	F_{RF} [MHz]	h
P	18	18.03	92.20	91.44	20.00	2
P	25	25.88	92.25	91.06	11.90	1
P	27	27.66	92.89	91.14	12.20	1
P	29.37	28.61	89.77	90.53	12.83	1
P	30	31.59	92.89	91.18	13.00	1
P	40	40.78	91.76	91.06	14.85	1
P	65	63.88	91.58	90.94	18.304	1
P	70	71.51	92.80	91.44	19.00	1
^{3}He	43	44.43	93.28	91.30	17.98	2
^{3}He	45	45.00	92.80	91.22	18.10	2
α	40	40.00	92.70	91.22	15.00	2
α	60	60.37	93.48	91.49	18.15	2
α	65	67.27	93.30	91.49	19.17	2
α	100	100.86	92.82	91.30	11.72	1

CONCLUSION

A beam energy measurement system employing a set of capacitive type of beam pick-up probes has been designed and installed in one of the straight section in a beam line at NIRS-930 cyclotron.

The beam energy is determined to measure the spatial distance between the beam bunches extracted from the cyclotron, where suitable beam pick-up probes are set into the transport line. In the measurement, the two beam signals from the pick-up probes are superimposed by adjusting a position of the downstream-probe along the beam direction with watching the two signals displayed on an oscilloscope. In order to determine the beam energy quickly and accurately Multi-Channel-Analyzer (MCA) system has been applied, which is under progressing.

Several beam energy has been measured for proton, 3He2+, and α beams. The result shows that the septum position is directory influence on the extracted beam energy, and is also varied by a bump-field produced by the harmonic-coil in the excitation region, where reliability of the measurement system was less than ± 0.5 %.

The work will continue to improve the MCA system for more simply operation in the measurement, and to confirm the measured energy with an another means such as neutron TOF method by a reaction of [p (Li , p) n].

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