BEAM DIAGNOSTIC EQUIPMENTS FOR RIKEN RING CYCLOTRON AND ITS BEAM LINES

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Summary

The design of beam diagnostic system in the Riken Ring cyclotron and in its injection beam line from linac (RILAC) will be reported. The injection beam line is so long that a large number of diagnostic equipments, such as profile monitor, Faraday cup, slit system, emittance monitor and so on, are required to transfer the heavy ion beam.

Introduction

The beam line between a variable-frequency linac (RILAC) and the Riken Ring Cyclotron is designed to transfer a variety of ions from carbon to bithmuth with energies from 0.8 to 4 MeV/u depending on its charge-to-mass ratio. The beam intensities depend largely on the ion species, ranging from a few to 10^4 nA. The Ring cyclotron will multiply the beam energy by a factor of 17. The beam diagnostic system should catch the information about these kinds of beams and transmit it to the host computer with accuracy and rapidity.

In the following discussions, the diagnostic system will be divided into two categories, those in the injection beam line and inside the ring cyclotron.

Injection Beam Line

Figure 1 shows the illustration of layout of the beam diagnostic system in the injection beam transport line between the RILAC (the variable-frequency linac) and the RIKEN Ring Cyclotron . The beam line is so long as 65 m that the beam handling procedure along the beam line requires a large number of beam diagnostic equipments according to the local requirements.

The diagnostic equipments are such as profile monitor, Faraday cup, slit system, phase probe, emittance monitor and so on. Every probes and its actuator are built on a stainless steel flange (NW-100 type for the emittance monitor, CF152 for other probes). Some of these probes are shown in Fig. 2. Normally, these probes are mounted onto the diagnostic chamber.

Diagnostic chamber

Several types of diagnostic chambers, having different sizes and different port numbers, have been installed at the positions along the beam line according to the local requirements. The largest type has six ports for beam diagnostic equipments and vacuum pumps. The beam diagnostic probes are mounted to these ports at angles of 45, 135, 225, 315 deg. to the vertical axis. The space just above the chamber is reserved for the positioning procedure of magnets and vacuum chambers. These chambers are made of aluminum alloy, because of its low cost and low out gassing rate.

Profile monitor

Profile monitor is used for the measurement of the beam intensity distribution in three directions. These data permit the tomographical display of the beam on a computer crt. The principle of the measurement is on the basis of the wire scanning method shown in Ref.1 and 2. Probe head has three tungsten wires, as shown in fig. 1. Wires are 0.1 mm in diameter and gold-plated tungsten ones. They are strung with small coil springs and fixed on stainless steel arms. The probe head is fixed on the shaft and moved in linear

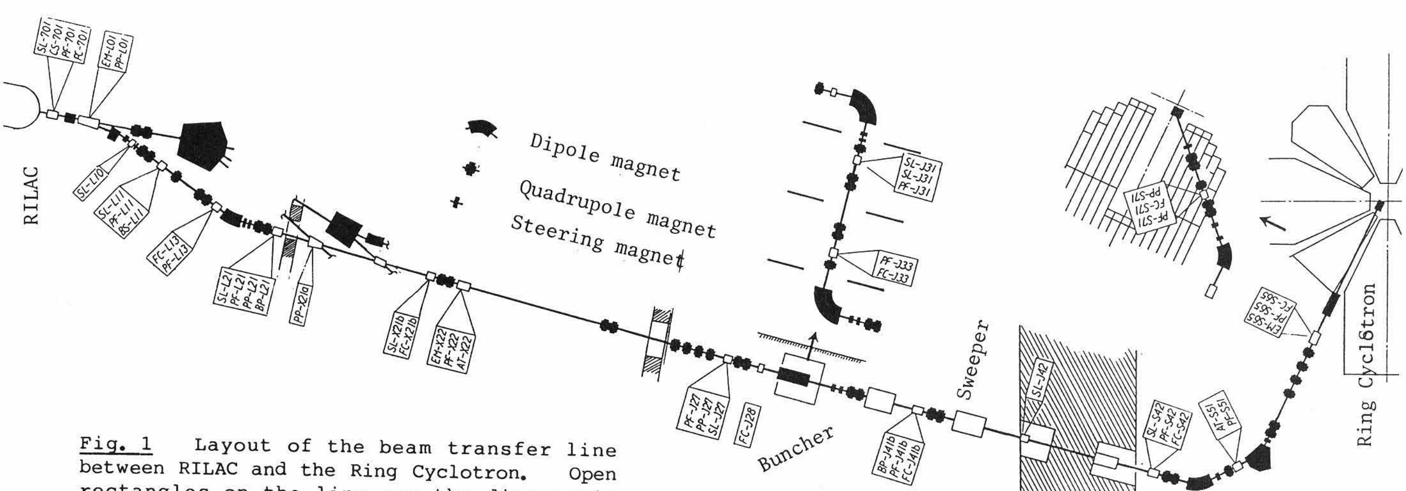

Fig. 1 Layout of the beam transfer line between RILAC and the Ring Cyclotron. Open rectangles on the line are the diagnostic chamber. The probes mounted there are shown nearby using symbols. First two letters of them show the probe name. PF: profile monitor, SL: slit system, FC: Faraday cup, PP: phase probe, EM: emittance monitor, CS: charge stripper, AT: beam attenuator, BP: bunch probe (coaxial Faraday cup).

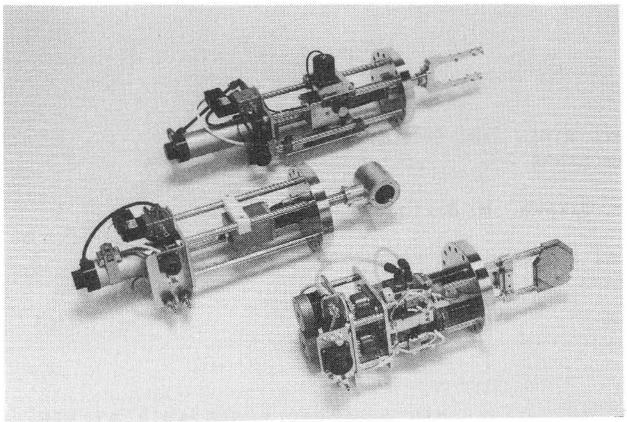

Fig. 2 Photograph of diagnostic equipments used in the injection beam line. The upper one is the profile monitor and the middle the Faraday cup, and the lower the slit system.

action by a stroke of 75 mm. The driver is a pneumatic cylinder. The scan speed is well controlled with a couple of air valve at both gas inlets to the air cylinder, being set around 75 mm/sec. The probe can be parked in both ends of the stroke. The sensitive region is within a circle with a diameter of 50 mm around the beam axis. The same region would be clearance for beam path when the probe is parked in the both ends of stroke. The vacuum seal is a stainless-steel welded bellow. The life of the bellow is not shorter than 10^5 cycles. One cycle gives two measurements. Absolute position of the probe head is known by two photo switches at both ends of the stroke. Relative position from these absolute positions is measured by a rotary encoder, which is rotated as the probe moves via rack and pinion gears. The position resolution is 0.08 mm. The probe is mounted on the diagnostic chamber at angle of 45^o to the vertical axis in normal case. Therefore the beam distributions along the horizontal, vertical and 45^o lines can be obtained.

Faraday cup

As shown in Fig.1, there is at least one Faraday cup in every straight beam line. They will aid the estimation of the beam transmission. Some of them works as a beam stopper under control of the radiation safety system for man and the protection system for equipments which is inserted in beam line accidentally. Rough but rapid estimation of beam transmission along the beam transport lines can be made with a non-destructive intensity monitor. It is using the ionization of residual gas in beam pipe. It consists of a pair of parallel plate electrodes, between which beam passes through. One electrode is biased at +100V and the other one is connected to the amplifier and kept at the ground potential. So the positive ions, which are produced between the electrodes by beam, are fed to the amplifier. The signal is proportional to beam intensity and vacuum pressure. After a proper calibration is done with a Faraday cup, the signal gives the information on beam intensity as far as the vacuum pressure is constant. The intensity monitor is set inside a beam pipe near to the diagnostic chamber. Its location is selected considering that it is far from the vacuum pumps to get more signal from the probe.

Phase probe

The beam phases with respect to rf accelerating system are measured with five capacitive phase probes. PP-L21, PP-X21a, PP-J27 are used for the precise measurement of beam energy. PP-S71 and PP-J41b are for tuning of the buncher. The probe has a ring-shaped electrode (its inner diameter is 38 mm and length 10 mm) and a 50-ohm coaxial signal line. The probe head is always fixed at the beam axis. The time structure of beam bunch are measured with a coaxial Faraday cup (beam destructive type). It will be helpful for the phase measurement, when beam intensity is lower than 100 nA.

Emittance monitor

The transverse emittance of beam is measured with a combination of slit system and multi-wire detector system. The emittances in horizontal and vertical planes are obtained sequentially by the same equipments. The slit system has, on a cooled plate, two slits (0.1mm in width and 40mm in length) which are perpendicular to each other as shown in Fig. 3. The detector system has also two sets of 32-wire sensors (0.1mm in diameter, 0.35mm in pitch and 40mm in length), and they are mounted such that the centeral wires of each sensors have the same relative position as the slits above. The two systems are mounted onto independent vacuum feed through built on separate NW-100 flanges. A driver with stepping motor and ball screw moves each system in linear action by a stroke of 110 mm independently. Each position is known with a photo sensor and a rotary encoder. Two systems are mounted onto the diagnostic chamber in direction at 45^o to the vertical axis, the distance of the two being typically 400mm. So the angular resolution is 0.9 mrad. As shown in Fig.4, the first half of the stroke gives the horizontal emittance and the second half gives the vertical one, when the both systems are driven synchronously. The sensitive area is within a circle with a diameter of 30 mm around the beam axis.

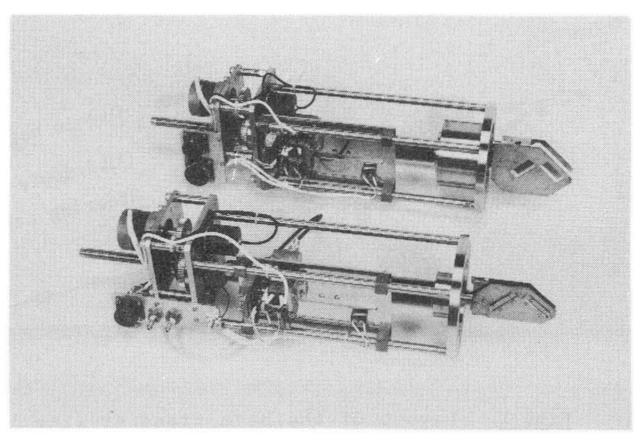

Fig. 3 Emittance monitor. The lower part is the slit system which is mounted upstream of beam line, and the upper is the detector system.

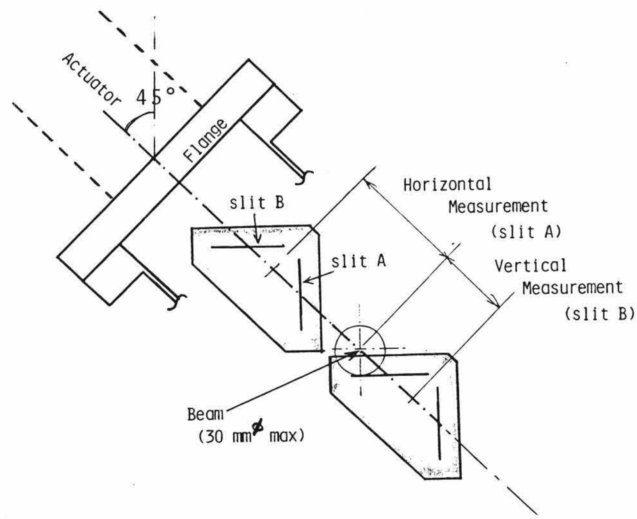

Fig. 4 The slit system of emittance monitor seen from upstream on the beam axis. The head of slit system is shown in two cases when it is at the both ends of the stroke. Slit A is used for the measurements of horizontal emittance, and slit B for those of vertical one. The multi-wire detector system moves in the same way.

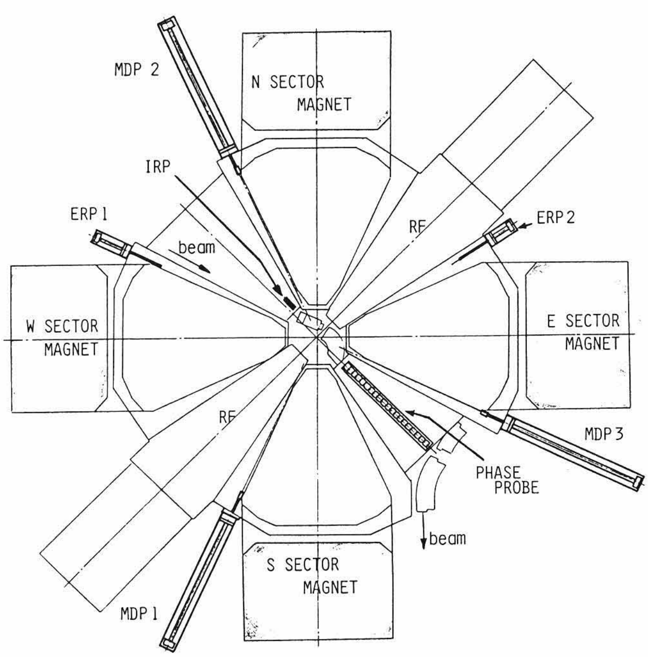

Fig. 5 Plan view of the RIKEN Ring Cyclotron. The layout of the beam diagnostic equipments is shown.

Diagnostic equipments in the Ring Cyclotron

The layout of the beam diagnostic equipments in the Ring Cyclotron is shown in Fig. 5.

Radial probe

Three types of probes are available for the measurements of beam intensity distribution in the radial directions of the Ring Cyclotron. They are the main differential probe (MDP), the injection radial probe (IRP), and the extraction radial probe (ERP).

MDP covers all the radial region from the injection to extraction orbits. Three MDPs (MDP1 - MDP3) have been installed as shown in Fig. 5. The probe head has three finger-like electrodes for the differential measurements. The central finger moves at the level of the median plane. The upper and lower fingers move at the levels of + 30 mm apart from the median plane. The sensitive region of these fingers are 0.5 mm in the radial direction and 8 mm in the vertical one. The electrode for the integral measurement is located in front of the fingers, and prevents the beam from hitting the insensitive regions of the fingers. The electrodes are made of copper block and pipe, and cooled by water independently. The region of electrode, which the beam hits directly, is covered by 2 mm thick tantalum plates. These electrodes are assembled on a ceramic block which is fixed on one end of stainless steel pipe with an outer diameter of 42 mm. The four liner plates, which are laid on the floor of the vacuum chamber along the probe path, support the pipe and keep the probe head at the median plane with an accuracy of 0.5 mm.

The probe is driven by a stepping motor and ball screw. Its stroke is 3500 mm, being long enough to bring the probe head completely outside the vacuum chamber for the maintenance. The probe heads moves along one of the pole edges of the sector magnets.

The absolute positions of the probe head is known by two mechanical switches at the both ends of the stroke and by four photo sensors which are set along the path. The relative position from one of these known positions are detected with a rotary encoder which are connected to the shaft of the stepping motor. The position resolution is 0.06m and the reproducibility is within 0.5 mm.

IRP and ERP have three directional wires as the profile monitor described above. In this case, however, the probe moves horizontally. IRP covers the 70 mm region outside from the injection orbit, and ERP covers the last 120 mm region from the extraction orbit. The driver of ERP is almost same as those of MDP, except that its stroke is 1200 mm. The driver of IRP is installed on the bottom of the valley chamber between the N and W sector magnets.

Phase probe

The relative phases of beams on different turns inside the Ring Cyclotron are measured in the valley vacuum chamber between the E and S sector magnets. The twenty pairs of capacitive phase probes have been installed along the central line of the chamber.

One unit of the phase probe has two electrode plates (upper and lower) which are parallel to each other. The plate is 100 mm x 100 mm in size and 3 mm in thickness. The upper electrode is fixed on the upper supporting arm at a level of 13 mm higher than the median planes and lower plate is fixed on the lower supporting arm at 13 mm lower than the median plane. Each electrode is covered by signal return plate except for the electrode surface facing to the beam as shown in Fig. 6.

The inside end probe is located at the radius of 940 mm, and the outside end electrode at that of 3125 mm. Other proves are arranged in a row between the two, sharing the constant separation. One probe feels the several turns of beam and the obtained phase is the average value of these turns.

The signal from each electrode is introduced into the 50-ohm coaxial signal line at the central point of the electrode, and, via coaxial feed trough, to the coaxial cables inside the supporting arm. The 20 cables with length of 5 m run inside each supporting arm and go outside the Ring Cyclotron. The two sets of the cables are connected to two 20:1 coaxial switches, respectively. The signal from upper electrode and from lower one are added, in order to improve a SN ratio, after the coaxial switches. The obtained signal is transferred to the control console, and there, observed on a osciloscope. The unselected signal lines are terminated through 50-ohm resisters to prevent the electrode from charging up.

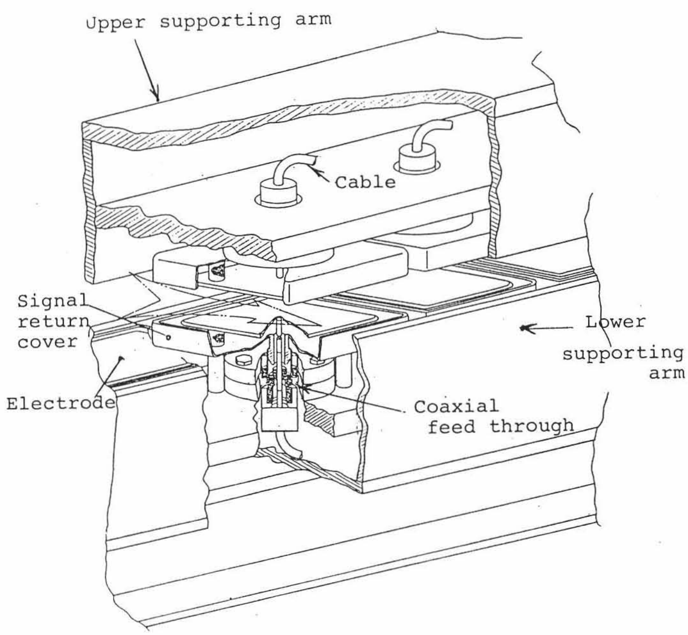

Fig. 6 Schematic drawing of part of the phase probe inside the Ring Cyclotron.

Electronics

Electronics for these beam diagnostic equipments are shown in Fig. 7. The system uses the CIM-DIM modules[3] as interface between the controlled device and CAMAC system. The circuits, which is located between the diagnostic probe and DIM, are devided into two types, BDI and BDA circuits.

The BDI-circuits, which are built in plug-in module, use the DIM digital in/out as a common bus line. A variety of circuits (up to 64) can be connected to one DIM module via this bus line, for example, vacuum system controller, interlock circuit, and also intelligent circuit such as radial probe controller. Analog signals from Faraday cup and slit system are fed into the log-amplifier and converted to digital signals in one of BDI circuit.

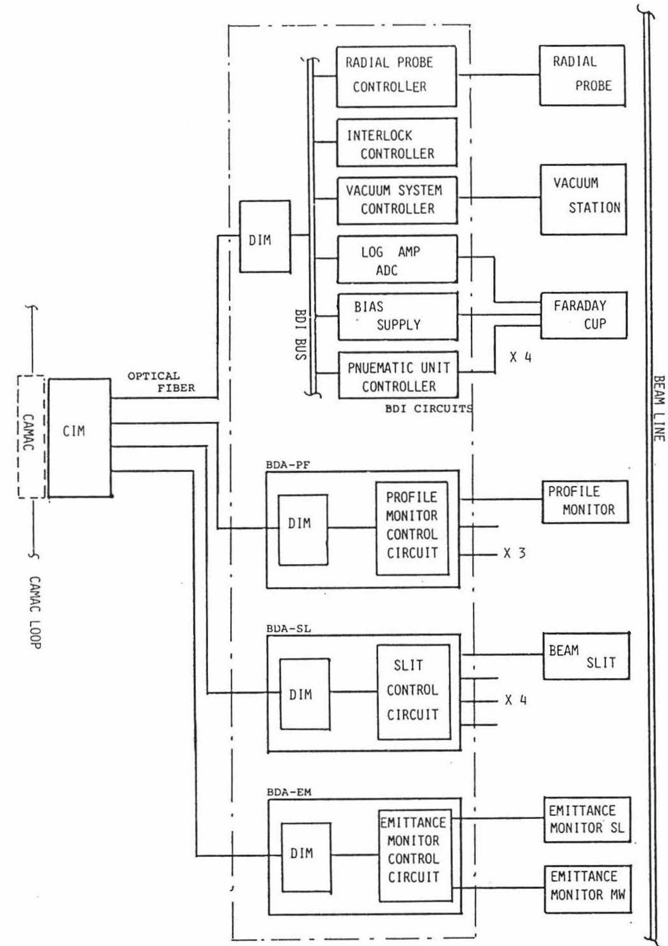

Fig. 7 Block diagram of the electronics for the beam diagnostic system.

Beam profile monitor, slit system and emittance monitor are controlled with BDA circuits. These circuits have two boards inside. One is DIM board and the other the probe control circuit. The latter board has counter for rotary encoder, driver for stepping motors and so on.

The circuits enclosed by dash-dott lines in Fig. 7 are mounted in a 19" rack which is called as beam diagnostic station (BDS). There are six BDS's along the beam transfer line and two BDS's around the Ring Cyclotron.

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