DESIGN STUDY OF A NONDESTRUCTIVE BEAM PROFILE AND HALOS MONITOR BASED ON RESIDUAL GAS IONIZATION FOR THE J-PARC RCS

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Abstract

A nondestructive beam profile monitor has been designed to measure density profiles and halos in J-PARC rapid cycle synchrotoron (RCS). The detector collects and amplifies the signal from the residual vacuum gas electrons/ions created by the beam passage. It can be expected to observe fast beam dynamics on timescale of a revolution period. The profile is determined by detecting the ionized electrons, guided in a strong magnetic field. The external field assures precision in the determination of the absolute beam profile and prevents the detection of background electrons originated outside the monitor's active volume. In this paper, a design and construction of nondestructive residual gas ionization profile monitor are described.

INTRODUCTION

Nondestructive profile monitor (NDPM) for circulating ion beams in synchrotron is important for both tuning and experiments of instabilities. The NDPM is also used to observe emittance growth and has been developed on several accelerators [1,2]. In these devices the residual gas electrons/ions produced by the beam are collected. Electrons produced in the ionization of atoms from a gas jet crossing the beam are detected in the LEAR [3]. The monitor detects ions to obtain a cross section of the beam in the KEK-PS [4]. In storage ring CRYRING, ionized electrons are detected with the magnetic field of a bending magnet to lower the background and increase position resolution [5]. However, it is difficult to obtain the absolute profile of high intensity proton beam due to collected electrons are diffused by intense space charge effect. Thus, additional magnetic fields are required to guide ionized electrons. The distortion of beam trajectory by external magnetic field has to be canceled. In this paper, we present the design and construction of a nondestructive diagnostic system to measure beam density profile and halos, based on the residual gas ionization and external magnetic field.

ESTIMATION OF IONIZED PARTICLE

The residual gas electrons/ions are created by the collision with the beam passing through the vacuum duct. The number of ionized particles is directly proportional to the both beam density and vacuum pressure. The energy loss rate of passing particle of atomic number z in a material of atomic number Z, density N is given by

$$-\frac{dE}{dx}=\frac{e^4z^2}{4\pi\beta^2m_0c^2\varepsilon_0^2}NZ\left\{\ln\left[\frac{2m_0c^2}{I}\left(\frac{\beta^2}{1-\beta^2}\right)\right]-\beta^2\right\}$$

and number of ionized particle n is

$$n=\frac{1}{I}\frac{dE}{dx}$$

where $\beta=v/c$, I is the ionization constant and m_0 is mass of electron. Although the composition of the residual gas in beam pipe is not known precisely, rough estimation of I~90 eV is enough to calculate the expected signals. The calculation result of ionized particles is shown in Fig. 1. Constant signal level is expected in energy range of 400 MeV~3 GeV. The RCS is a rapid cycle proton synchrotron. Its parameters are shown in Table 1.

Table 1: Assumed RCS parameters used in calculation of expected signals.

Circumference	348 m
Particle type	Proton
Injection energy	400 MeV/181 MeV
Extraction energy	3 GeV
Number of particles	8.3×10^{13}
Acceletation cycle	40 msec
Beta function	7 m (at NDPM)
Vacuum pressure	1×10^{-6} Torr

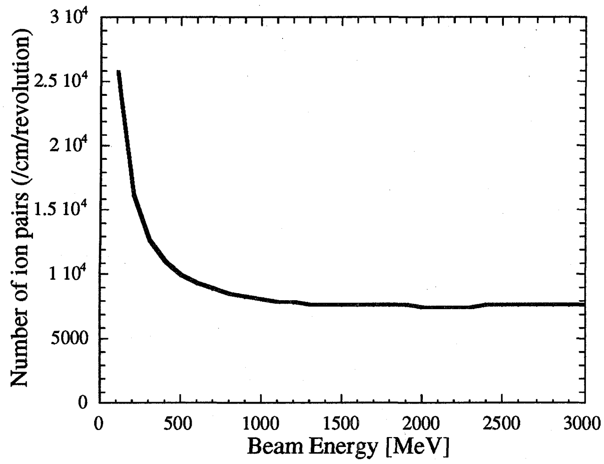

Figure 1: Calculated result of number of ionized particles in a revolution period.

EXPERIMENTAL APPARATUS

Schematic layout of NDPM system is shown in Fig. 2. The system consists of electrodes for electrostatic field, a wiggler type magnet to obtain the absolute beam profile and three multichannel plate (MCP) assembly of 30mm×80mm active area. A central MCP detector is equipped to measure beam core region, and others are used to investigate the behaviour of beam halos (Fig. 3). The bias voltage for each detectors and gain of preamplifier can be controlled separately.

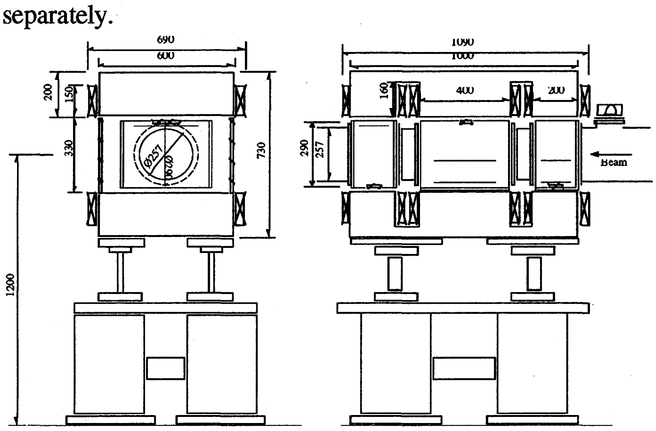

Figure 2: Schematic layout of the beam profile monitor. The proton beam ionises the residual gas atoms. The products are driven electrostatically towards the MCP detectors with gyromotion around the external magnetic field lines.

The applied electrostatic field has to exceeds the field induced by space charge (~1kV/cm). In order to collect ionized particles, power supply of 40 kV is prepared for RCS large vacuum pipe (~300 mm). The high voltage is also preferred to examine the ion collection because the time resolution is limited by average drift time to MCP plate.

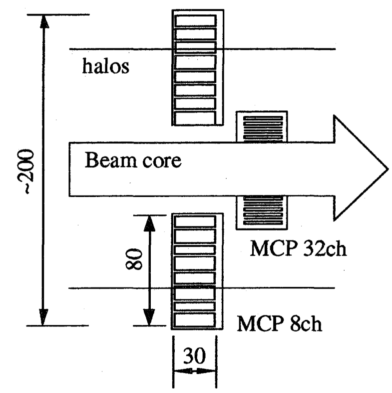

Figure 3: Schematic of MCP detectors. Center detector of 32 channel observes the core density profile. Others of each 8 channel are prepared to investigate the beam halos.

Difficulty of NDPM in the J-PARC RCS is originated in the strong space charge effect by intense proton beam.

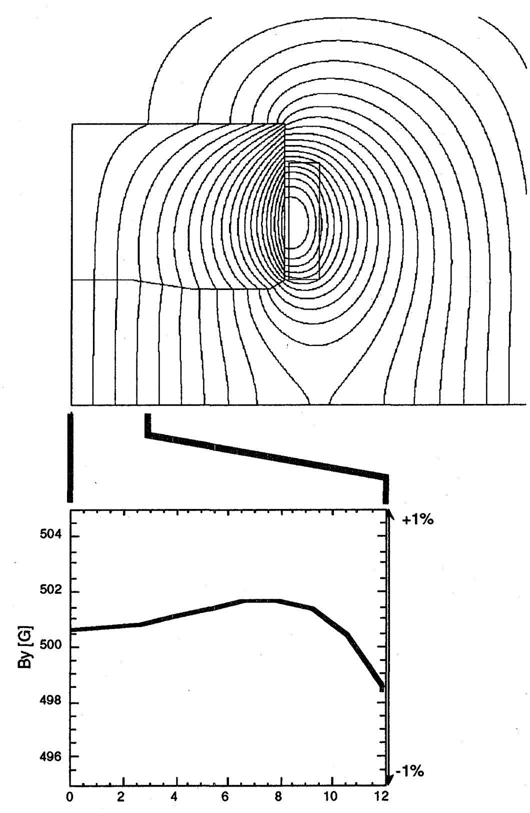

Figure 4 (a): Calculated field distribution in X-Y plane.

External magnetic field is designed to suppress the diffusion of ionized particles. A two-dimensional simulation of model magnet is performed. Figure 4 (a) shows magnetic field lines in X-Y plane. Sufficient homogeneity of magnetic field less than ±0.2% for active area is obtained.

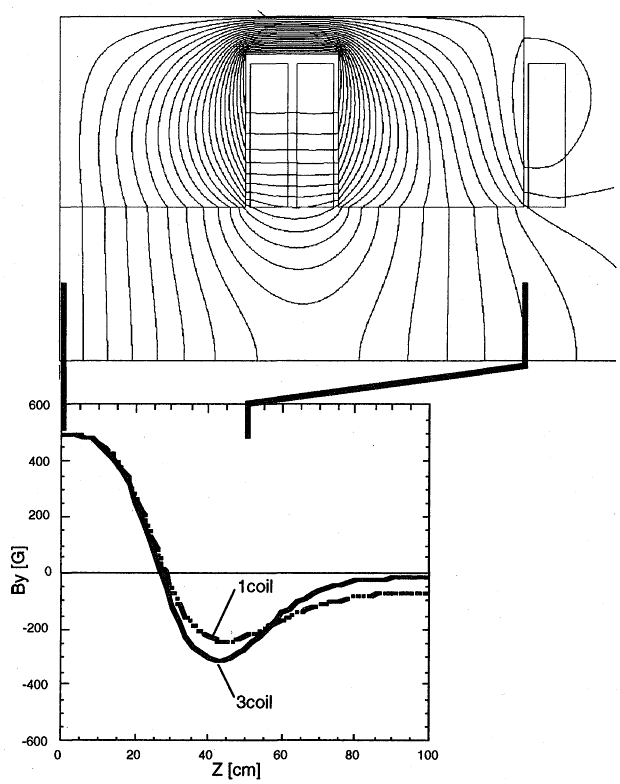

Figure 4 (b): Calculated field distribution along the beam line.

Figure 4 (b) also shows the side view of a designed model magnet. Divided three poles in longitudinal direction are need to cancel the distortion of beam trajectory.

Coil winding forms of both only center pole and contain three poles are examined. It is clear that the stray field of three-coil system is smaller than the stray field by single coil. In this estimation, it was also found that magnetic force of about 6000 A-turn is required for each coil to obtain the magnetic field of 500 G at beam position.

SUMMARY

A nondestructive beam profile monitor was designed to measure high intensity proton beam in the J-PARC RCS. The NDPM consists of three MCP detectors, 40 kV electrostatic field for electrons/ions collection and 500 G wiggler type magnetic field to determine the absolute profiles. The NDPM system contributes to survey the instabilities or other intense beam physics, and investigates the behaviour of beam halos. However, it is indispensable to evaluate the performance of NDPM system practically. The ionized particle motion should be confirmed in the area of intense electrostatic and magnetic fields are overlapped. Experimental studies using a prototype in the KEK-PS or other accelerators are essential to develop the NDPM for the J-PARC RCS.

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