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Technical issues of 3GeV synchrotron for JAERI-KEK joint project

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Abstract

The 3GeV synchrotron ring for JAERI-KEK joint project supplies high intensity proton beam to both the 50GeV synchrotron ring and the neutron production target. For this purpose, the 3GeV synchrotron aims to generate a high power beam of 1MW by setting 25Hz as the repetition rate of acceleration and 8.3×10^{13} as the proton number per acceleration. This paper describes the technical issues of the 3GeV synchrotron in order to realize such a high power and high repetition ratio.

1. Introduction

Japan Atomic Energy Research Institute (JAERI) and High Energy Accelerator Research Organization (KEK) have been performing to the joint project of a high intensity proton accelerators. The accelerator complex is a 600MeV linac, a 3GeV rapid cycle synchrotron, and a 50GeV synchrotron ring.

The 3GeV synchrotron ring accelerates a proton beam from the 400-600MeV Proton Linac up to 3GeV and supplies it to the 50GeV synchrotron ring. The 3GeV synchrotron ring also supplies the neutron production target with the 3GeV proton beam in order to produce a high intensity neutron beam. For this purpose, the 3GeV synchrotron ring aims to generate a high power beam of 1MW by setting 25Hz as the repetition rate of acceleration and 8.3×10^{13} as the proton number per acceleration. There are a lot of key issues which are had to solved technically in order to realize such a high intensity rapid cycling synchrotron. This paper describes the technical issues of the 3GeV synchrotron ring.

2. Technical Issues

2. 1Magnet

Since the repetition rate of the 3GeV synchrotron ring is 25Hz, the magnet core has to be fabricated by stacking thin iron plates. In the case of a rapid cycling magnet, the end shape of the magnet core must be carefully designed so that an eddy current, which is induced by the perpendicular component of a magnet field to the end plate, does not heat up the magnet end plate. Furthermore, a stranded conductor is used as a coil conductor in order to reduce the eddy current. The aluminum-stranded conductor was developed about fifteen years ago at KEK and has been used as the coil conductor of a pulse magnet in the BSF line at KEK [1]. This magnet has been operated without any trouble for fifteen years. So this type of magnet is candidate for the lattice magnet of the 3GeV synchrotron and has been performed to being developed for the 3GeV synchrotron. The magnet parameters are listed in Table 1.

Table 1 The magnet parameter list.

	Bending Magnet	Quadrupole Magnet
Maximum Magnetic Field (T)	1.1	
Maximum Magnetic Field Gradient (T/m)		4.5
Minimum Magnetic Field (T)	027	
Minimum Magnetic Field Gradient (T/m)		1.19
Core Length (mm)	2770	730
Pole Gap (mm)	210	
Bore Radius (mm)		140
Size of Stranded Conductor (mm^2)	30 x 30 (pipe inner dia.=12mm)	20 x 20 (pipe inner dia.= 6mm)
Coil Turn Number (Turn/Pole)	36	32
Good Field Regions	±95 for horizontal ±88.5 for vertical <±5x10^{-4} for precision	±120 <±5x10^{-3} for precision
Magnet Weight (ton)	35	12

2.2 Power Supply

A programmable excitation of synchrotron magnet is desired from the standpoint of accelerator operation. However such operation is so difficult for a rapid cycle synchrotron with a repetition of more than 10Hz which are excited using a resonant network. Resonant power supply system for one family of magnets and network parameters for dipole string excitation are shown in Fig. 1 and Table 2, respectively. The circuit consists of a magnet inductance Lm, which may include two or more magnets, an effective inductance of a choke secondary winging Lch, and a resonant capacitor Cm. There are two types of a resonant circuit, one is a parallel resonant circuit and the other is a series resonant circuit. The series resonant circuit is a first option for our system. There are some research and development items for the series resonant circuit in order to be in stable operation. The R&D items include (1) IGBT power supply, (2) B/Q tracking saturation compensation, (3) Smoothing of power variation, (4) Flat bottom formation, and (5) Trim for quadrupole magnets.

IGBT power supply, with low harmonic contents and broad bandwidth, has been developed for the resonant excitation system. Dipole and quadrupole strings are excited separately. Using IGBT power supplies, field tracking is feasible with current feedback. Moreover, field saturation can be compensated by means of harmonic manipulation. Power variation of the ac line is smoothing within about 10%. Flat bottom formation has been demonstrated. Trim option for quadrupole magnets is being discussed and a scheme for powering the trim coils is being evaluated.

Table 1 Network Parameters for Dipole-string Excitation

Dipole magnet : Lm	59.6 mH
Choke : Lch	59.6 mH
Condenser : Cm	1.36 mF
Excitation Frequency : f0	25 Hz
Mesh number	24 + 1
Idc	1606 A
Iac (amplitude)	977 A
Q factor	75
Pac (AC power loss)	3.0 MW (total)
Pdc (DC power loss)	3.5 MW (total)

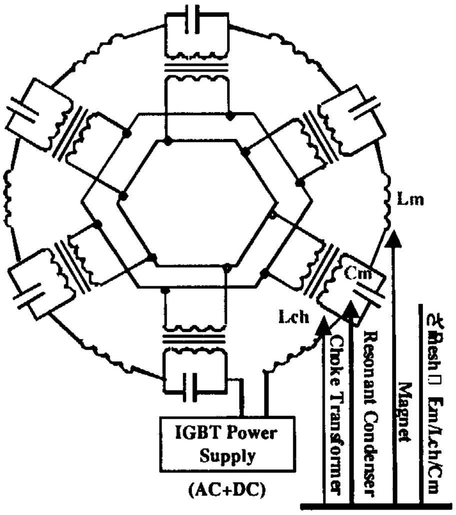

Fig.1 1 Resonant Power Supply System for One Family of Magnet

2.3 Vacuum

In rapid cycling magnetic field of 3GeV synchrotron, an eddy current effect in the metal duct would produce an unacceptable perturbation of the magnetic field and unnecessarily large ohmic losses. A ceramic duct is a better choice in the dipole and quadrupole magnets. Since a long ceramic duct can only be manufactured by glazing duct segments, the mechanical strength and deterioration in the glazing joint must be examined. Using a ceramic duct, a radio frequency shield is necessary between the beam and the laminated magnet structure to lower impedance of the image current induced by the beam. The shield is to be designed as a high frequency pass filter, where any eddy current cannot be generated. The impedance of the shield is affected by the skin depth, which is electrical conductivity of the shield material, and by geometrical structure. Connection to a flange of bellows should be geometrically smooth.

The required beam apertures and duct dimensions are given in Table 3. During the stage of injection followed by acceleration, the ducts in both the dipole and quadrupole magnets can have circular cross section of 177mm and 247mm in diameter, respectively.

Table 3 The requirements of beam aperture and duct dimension.

Magnet Type	Magnet Bore Dimension (mm)	Length (mm)	Duct Cross-section	Inner Diameter (mm)
in Dipole	210 (gap)	3000	Circular	> 177
in Quadrupole	280	1000	Circular	> 247

The thickness of the alumina ceramic duct can be reduce to 4 or 5 mm when the cross section of the duct is chosen to be circular or quasi circular, using a ceramic having a sufficiently high flexural strength (more than 300 MPa). Since a ceramic mold is generally deformed during sintering in a furnace, an alumina ceramic duct 3.5 m long and 177 mm in diameter is difficult to make with accuracy in the radial dimension, when the entire duct is fired at once. It can only be manufactured by jointing duct segments 500mm long. There is two type of joint method of alumina ceramic. One is a glazing joint and the other is a metalizing and glazing. The mechanical strength of these joint methods was measured for one of the alumina ceramics in terms of tensile strength so far, showing a value of more than 120 MPa due to glazing joint and more than 270 MPa due to metalizing and glazing [2]. The flexural strength should be examined for various kinds of alumina ceramics, since the strength of the joints depends on the microstructure of the ceramics as well as on the micro bubble density in the glass. Since deterioration in the strength under irradiation also depends on the microstructure of the glass and ceramics, the measurement of the strength of the ceramic under irradiation has been performing.

2.4 Halo Collection

From experience of the accelerator operation, the average beam loss should be kept at an order of 1 watt per meter for hands-on maintenance. The ration of the beam loss to the output beam power is then as low as 10^{-3}. Since it is very difficult to control the beam loss at such a low level, the only measure we can take is to localize any of the losses in a restricted area, where deliberate modules should be provided for quick coupling and remote handling in order to mitigate the personnel doses. In order to localize the beam loss the beam loss distribution around the ring has been calculated with Monte-Carlo simulation code STRUCT [3]. Since the collimator system intercepts the penumbra of the circulating beam, the initial distribution of proton is given in such a way that the particles only exist outside the maximum emittance 216π mm.mrad, the density of which is inversely proportional to the distance from the phase-space origin. The momentum spread is also included with a spread of $\pm 0.5\%$. The number of traced particles is 10000 to simulate. A STRUCT calculation shows that more than 90% of traced beam is lost around the ring for the collimation system. The energy deposit per meter at each element is shown in Fig. 2, where the loss is assumed to occur at 400 MeV at 25 Hz repetition and 4 kW loss.

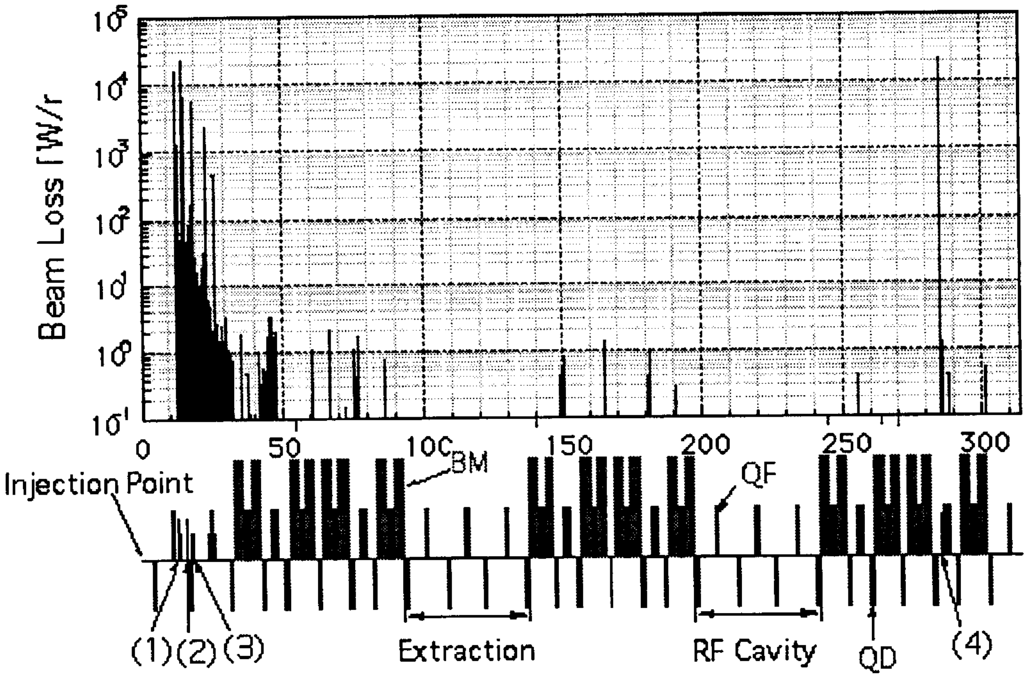

Fig. 2 The energy deposit per meter at each element calculated by STRUCT code.
(1) Primary Vertical Target, (2) Primary Horizontal Target,
(3) Secondary Collimator, and (4) Primary Longitudinal Target

3. Summary

The research and development for the 3GeV rapid cycling synchrotron have been performed to realize a high power proton beam. The key issues of this rein as follows.

(1) Magnet

A aluminum stranded conductor has been developed for the conductor of the magnet.

(2) Power Supply

There are some research and development items for the series resonant circuit in order to be in stable operation. The R&D items include the IGBT power supply, the B/Q tracking saturation compensation, the smoothing of power variation, the flat bottom formation, and the trim for quadrupole magnets.

(3) Vacuum Duct

Alumina Ceramic vacuum duct with RF shield has been developed. The thickness of the alumina ceramic duct could be reduce to 5 or 6 mm.

(4) Halo Collection

In order to localize the beam loss the beam loss distribution around the ring has been calculated with Monte-Carlo simulation code STRUCT. This calculation shows that more than 90% of traced beam is lost around the ring for the collimation system.

(5) Othes

There are lot of key issues for this ring, for example injection and extraction pulse magnet and these power supply , radio frequency cavity, monitor and so on. The research and development are also performing for these issues.

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[3] I. Baishev, A. Drozhin, and N. Mokhov : "STRUCT Program user's reference manual", SSCL-MAN 0034, February 1994