SYSTEM DESIGN OF MAIN MAGNET POWER SUPPLIES OF THE HIMAC HEAVY-ION SYNCHROTRON

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Abstract

The HIMAC is a Heavy-Ion Medical Accelerator in Chiba at the National Institute of Radiological Sciences(NIRS).This paper describes an overview of the system design of main magnet power supplies of the HIMAC heavy ion synchrotron.

Introduction

HIMAC main synchrotron[1] is composed of two rings. They are located in vertically separated floors. Main objective of the design of power supplies is a reduction of current ripples and firing noise of the thyristor in synchrotron magnets, a proper power regulation of a reactive power in a systematic design of power supplies, magnet coil and SVC. Current ripples could range from fundamental frequency to 12th harmonics due to imbalance of primary ac line voltage although it is 12th harmonics only ideally without the imbalance This tolerance during a slow extraction of 400 msec is known to be very tight indeed , tighter than that of realizable with a state of the art of the technology of a conventional method. The power supply of dipole and quadrupole magnet uses a 24 pulse thyristor rectifiers. The lower frequencies which might be generated by an imbalance of each pulses ,50 Hz to 600 Hz, is expected to be suppressed by repetitive control algorithm developed by Matsumoto et al. at KEK[2),3)]. Complimentary new method to reduce the 50 Hz ripple is also under study as shown in later paragraph by the help of a reactive power compensator. The reduction of ignition noise of the thyristor is expected to be realized by our novel combination of various methods:

(1) symmetric separated functioned normal and common mode DC filter.

(2) parallel bypass resistor .

Reactive power of the magnet is compensated so that the induced voltage fluctuation to the power grid is made to a small level from our power supply . We have provided a reactive power compensation device, thyristor controlled reactor or high impedance transformer , lead capacitor and higher harmonics filter, etc.. An excitation current is assigned by a pattern of digital voltage as in KEK. It has been demonstrated that the repetitive control algorithm is very effective for this type of operation[2),3)]. We will follow this system and propose complimentary method for further improvement of the system. It is worth to note that a full synchronization of each pattern is important for a better current tracking among various patterns, for the reduction of parasitic harmonics, for a ringing phenomena due to firing noise , etc..

Novel wiring method of the coil - symmetric cross- over connection

In order to reduce an asymmetric field distribution as well as the current spikes associated with a switching noise of the thyristor, following measures are considered:

(1) An upper and lower excitation coils of the magnet is separated and interchanged at each magnet , which is called here as a cross-over connection; a twisted loop is formed as shown in Fig.1 .

(2) All iron yokes of the magnet are connected altogether and they are also connected to a neutral point of the power supply. The neutral point will be physically grounded to ensure potential reference.

Main power supply

Main parameters of the power supply and its load are given in Table1. To achieve an efficient energy conversion, we chose a thyristor power converter system . The choice of 24 pulses rather than 12 pulses is expected to suppress the current ripples and to improve voltage feedback characteristics, more efficient than that of 12 pulses rectifier in the repetitive pattern control algorithm. The rectifiers for the dipole magnet consist of 8 blocks of 6 pulse thyristor bridge and each bridge has a bypassthyristor. The blocks are assembled in a symmetric fashion around the neutral point. The rectifiers of the dipole magnet power supply are operated in converter-inverter mode[4)]; in case of low voltage operation one rectifier is operated in converter mode with large positive phase angle and another one is operated in inverter mode with large negative phase angle to suppress the total reactive power. The rectifiers of the quadrupole magnet

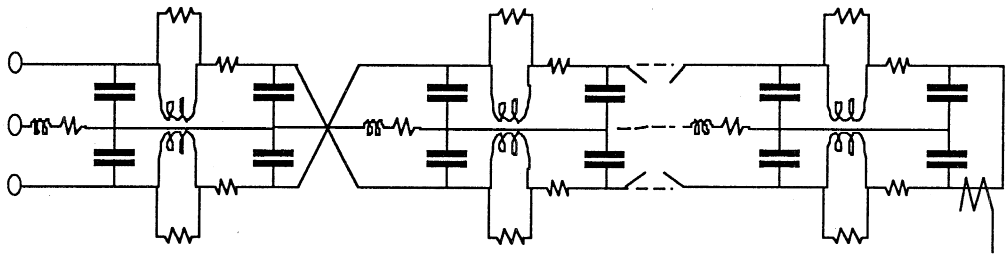

Fig.1 Symmetric cross-over connection

power supply are operated in converter mode. We have provided normal mode filter and common mode filter for a passive filter. We assume the excitation current in the upper and lower coil is not identical. The normal mode filter is effective for a sum of the current of the upper and lower coil of a magnet whereas the common mode filter is effective for a difference of that of the upper and the lower current.

Table 1
Main parameters of the power supplies and loads.

Power supplies		
stability goal	2*10^(-5)	
repetition (Hz)	0.3-1.5 at 600 MeV/u	
rise/flat-top period(s)	0.7/0.5 typical at 0.5 Hz	
field change rate (T/s)	2	
Load	dipole	quadrupole
output power(MW)	5.13	0.538
voltage(kV)	2.27	0.32
current(kA)	2.26	1.68
inductance(13 units) (mH)	670.8	58.7
resistance (mOhm)	250.9	116.8
cable resistance(mOhm)	12	

Two ring operation

We have two synchrotron rings with almost identical structure. Two ring system is flexible and reliable from a view point of steady operation because one of the rings could be back-up ring of the another under single ring operation. This is a very important feature for a medical use machine. Other advantages of the two ring operation is a simultaneous beam irradiation of independent, vertical and horizontal beam of different beam energy, an economic way of reducing total power variation which is a sum of an effective power and a reactive power by an out -of- phase operation of the power supplies of the two rings. A typical maximum reactive power of single ring operation ,where a repetition period is 3.3 second and a rate of field change is 2 T/s for an ion energy of 800 MeV/u, is 5.4 MVar, whereas for a two ring operation it is 6.8 MVar. It can be shown that the reactive power under the case of two ring operation could be reduced to 6 MVar only by modifying a duration of a flat bottom.

Static Var Compensator (SVC)

On a routine pulse opeation , constant reactive power of the power supply is requested by other users or devices of the site to keep a variation of primary ac line voltage steady as possible, although this is not mandatory directly to the synchrotron magnet itself. This is compensated by a 12-pulse thyristor controlled reactor in collaboration with lead capacitors and higher harmonic filters. It may worth to note that 66 kV high tension transformer is equipped with automatic tap-changer . It may also be worth to note that the thyristor controlled reactor is connected to high impedance transformer for decoupling purpose of primary and secondary windings. The reactive power compensator also plays an important role to reduce the phase imbalance of primary ac power line voltage. This role is an important feature in our 24 pulse rectifier system because illogical second harmonic component,100 Hz, is generated by it. A detailed study of SVC is now under way.

Suppression of a current spike due to thyristor firing

We have observed a decaying oscillation,current spike, in many thyristor controlled power supplies. This oscillation is generated as a series resonance of magnet loads excited by an ignition noise of the rectifier thyristor. It can be shown that an amplitude of this resonance is reduced for the current difference of the upper coil and the lower coil of the load magnet because of an expected high load impedance in our configuration . We have common mode filter for the current difference of the upper coils and lower coil and also normal mode filter for current sum of the coil . Residual current spike is further reduced by bypass resistors across the terminals of the coil input and output . Bypass resisters also could play an role to suppress the reflected signal of the spike. These resistors were demonstrated to be effective by preliminary test at Institute for Nuclear Study (INS) , a cooler - synchrotron ring TARN2.

Capacitors of a snubber circuit is made to be exchangeable so that one could shift the frequency of the source of the current spikes.

Pattern Control

An excitation current of the magnet is specified by pattern signals of the current and the voltage. This is a repetitive feed-forward pattern control system. The success of the pattern control system may depend on how well one could develop a good model to simulate the actual load. A preliminary data of a transfer function between excitation current and a magnetic field information is obtained from a data of magnetic field measurement. It was shown that one could write down the current by a polynominal expansion of the field strength by n=1 to 11 with an accuracy of better than 0.1 %.

Main characteristics of the pattern control is;

(1) The control signals of all the power supply as well as the Static Var Compensator (SVC) ,are synchronized to a single synchronization signal,whcih is synchronized to ac line voltage to suppress the illogical interference.

(2) Repetitive control of the pattern signal.

(3) Tracking control by the repetitive control among the power supplies of various magnets.

(4) Reduction of illogical harmonic components by the repetitive control.

For further improvement of the repetitive control system, we are considering to implement;

(5) Fine adjustment of the pattern shape.

By rounding off the shape of the rising part of a trapezoidal pattern shape, it is shown that,Fourier components of the harmonics could be reduced.

(6) Fine adjustment of the timing of the rising part with respect to that of the phase of the ac line voltage. This is based on the fact that a proper choice of the input signal to the reactive load leads one to be free from transient phenomena.

Timing system

All power supplies related with pattern control refers to the 1200 Hz,50 Hz times 24 pulses,event or controle (timing) clock. This event signal is phase-locked to the primary three phase ac line voltage and consists of 16 bit data as shown in Fig.2. The pattern signals of the current and voltage are initiated by the command signal such as BUMP ON,INJECTION REQUIRED,RF START,etc.,whose phase is locked at an intervals of any integer times period of 20 ms. And the details of the pattern is specified by the event data as an increment of a memory address. The event (timing) signal is generated from the 16 bit event data with arbitral delay length.

Acknowledgment

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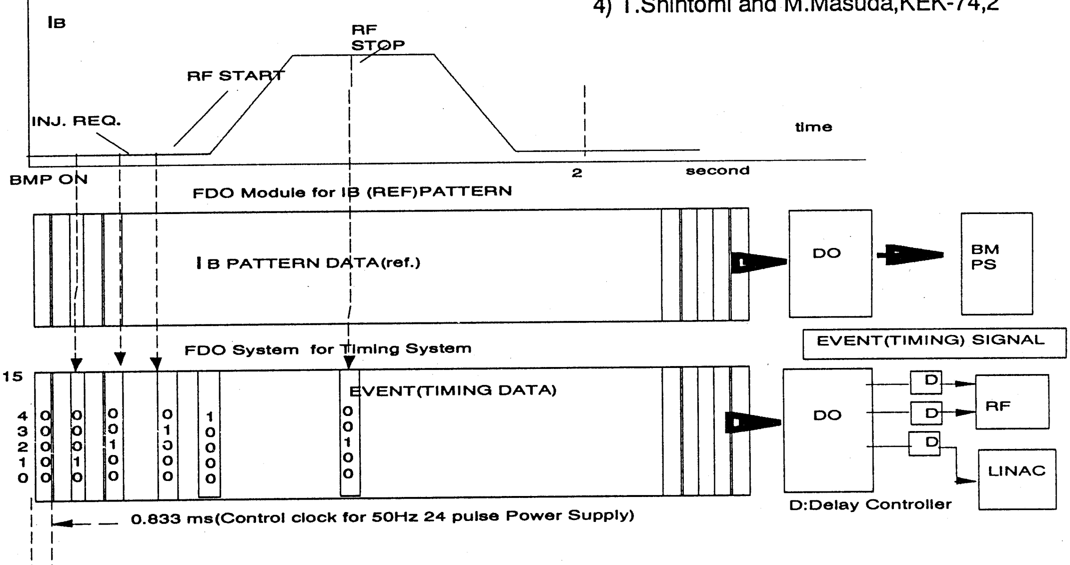

Fig.2 Block diagram of the timing system