INDUCTION SYNCHROTRON (3) : RAPID CYCLE SYNCHROTRON AND SLOW CYCLE SYNCHROTRON
(HARDWARE COMPONENTS FOR THE UPGRADE OF KEK 12 GEV-PS)

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Abstract

A technique of super-bunch acceleration with high repetition induction accelerators and an accumulator ring (AR) are required for the upgrade of the 12 GeV proton synchrotron at KEK. A fast dynamic switching of 3 kV flip-flop pulses was performed at 200 kHz with SI-thyristors, to confirm a barrier bucket scheme for induction acceleration finally. On the other hand, a model permanent gradient magnet for the AR was assembled to investigate its field quality, a temperature dependence and its compensation.

1 INTRODUCTION

A proposal for a major upgrade of the KEK 12 GeV-PS [1] is presented for the first application as an induction synchrotron [2]. The proposal involves a combination of beam stacking in a 500 MeV accumulator ring (AR) and acceleration of a super-bunch in the 12 GeV main ring (MR), referred to as the Intensity Doubler (ID). It takes 0.4 s to complete every injection of nine bunches from 500 MeV rapid cycle booster synchrotron into the MR now. The AR is capable to inject in one-turn and play a role of shortening the MR cycle of 2.2 s. The super-bunch acceleration is the way to increase a bunching factor from 0.3 to 0.7 using short and high barrier potentials and long acceleration field, called “a barrier bucket”. The electric field which a beam transits must be complicated to compared with the traditional RF field. A high repetition modulator to produce an induction field is required here.

The important issue lie on the development of high repetition / high voltage switching to produce the trapezoid pulses onto induction cells for high field barrier bucket and acceleration. The field-effect-transistor (FET) and static-induction-thyristor (SIth) [3] are being attempted for the high repetition switching. SI-thyristor is a new high speed switching element, which is capable to both switch ON and OFF. The electrical performance at 100 k pps with FETs was reported in ref.4. In this paper, the result of 200 kHz switching with SI-thyristor is presented. One element of the SI-thyristor can operate at high voltage of 3 ~ 6 kV, so it is possible to reduce the number of gate triggering lines and those control systems, in comparison with FET switching. The operation at 100 V / 800 kHz, which is near the frequency of 882 kHz required for the upgrade proposal, with FETs has been also achieved in burst mode and its result will be reported soon. It is also applicable at 441 kHz but two times higher field. The beam loading and other problems on induction accelerator device are discussed in ref. 5.

Another issue is how to save costs to construct the AR. A combined FODO lattice was designed and 88 gradient magnets are required to have BL = 0.238 Tm and GL = 0.575 T within the 70 mm vertical gap height and a +/-50 mm horizontal good field region. The permanent gradient magnets have been chosen for main bending and focusing. A strontium ferrite material has been selected due to its cheap cost and gives sufficient field to keep 500 MeV proton beam in the 350 m AR. But the material has a weak temperature dependence in magnetic field and this is crucial to control the beam orbit in the actual tunnel environment with a variation of +/-3 degrees at least. The use of Ni(30%) Fe(70%) alloy operating near its Curie point is expected to compensate a gap field degradation due to the temperature variation.

2 HIGH REPETITION MODULATOR FOR INDUCTION ACCELERATION

The test stand was constructed for the 3kV / 200 kHz flip-flop dynamic switching modulator. A main positive pulse, effective to the acceleration or forming the barrier bucket, and a negative pulse, which resets a core magnetization, are necessary for a stable working of the induction acceleration device. Figure 1 shows the overview of the switching circuit using four SI-thyristors.

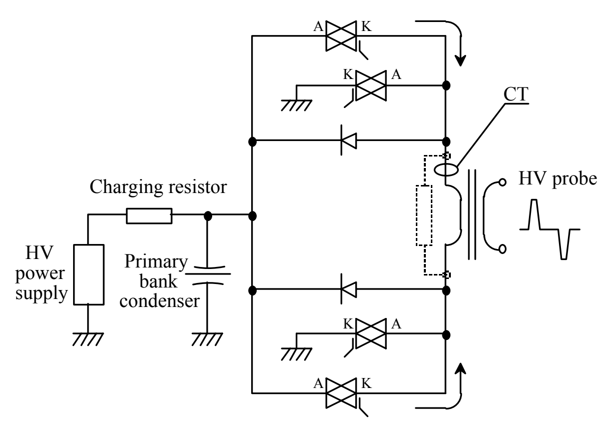

Figure 1: Flip-flop switching circuit.

Each switch element acts as ON/OFF for positive/negative pulses respectively in turn. Figure 2 shows the test stand of modulator assembly. Four SI-thyristor elements are stacked in vertical.

Figures 3 shows the experimental results under the 3 kV / 200 kHz operation. The flatness of the loop voltage is quite good. It seems that the induced voltage decreases slowly. This is due to the insufficient bank condenser for the experiment. A new modulator aiming to achieve 500 kHz operation is now under designing.

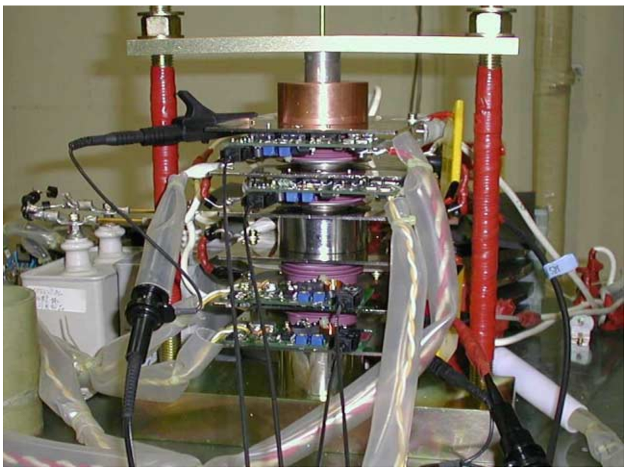

Figure 2: Test stand of modulator assembly.

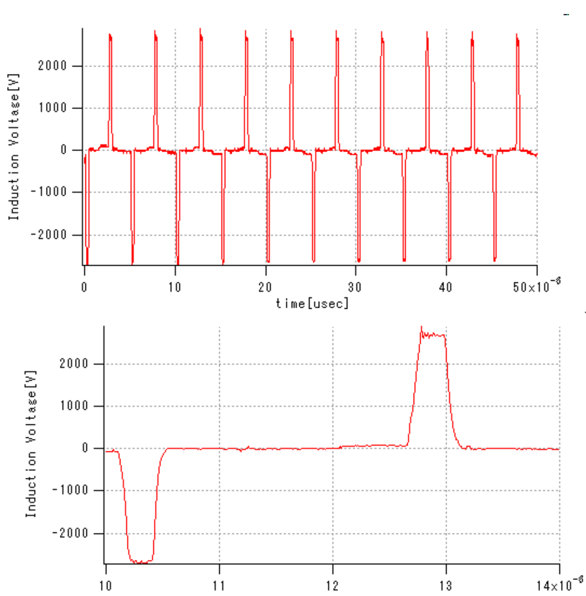

Figure 3: Induced one-turn loop voltage Measured at 3 kV / 200 kHz operation(upper); expanded wave form(lower).

3 PERMANENT MAGNETS FOR AR

A model gradient permanent magnet one meter long was assembled to confirm the field quality and temperature compensation technique [6, 7]. Figure 4 shows the cross-section of the model magnet, with a 70 mm gap at the center and a 230 mm horizontal aperture. This is a 1m long straight magnet and designed to give the center field of 0.13 T and the gradient of 0.31 T/m with a 980mm pole tip length. Three bricks of a ferrite, 100.6 mm × 222 mm × 25 mm, are stacked at both pole sides and drive flux vertically. The entire assembly is enclosed in a flux return shell 25 mm thick. Solid "bar stock" components are used throughout rather than laminations. The pole tip is made of SUYP1 low carbon steel and the flux return is construction grade (SS400) steel. The field of the magnet is terminated by flux clamp/end plates, which are magnetically connected to the flux return shell.

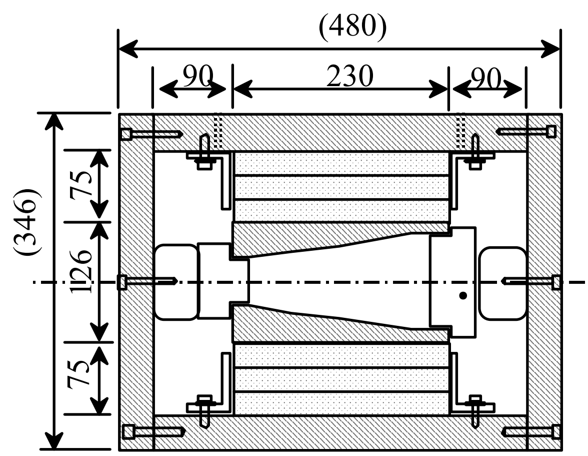

Figure 4: Cross-section of a prototype magnet.

Type SR-2 Strontium Ferrite (Tokin Corp.) is chosen as the permanent magnet material because of its low cost and of availability. Ferrite bricks have been magnetized using three pulses of 1.7 T, produced with a spare bending magnet of KEK 12 GeV-PS. The products are not so even, with +/-5 % difference, therefore those were shuffled and selected to be averaged in each unit, which is composed of three ferrite bricks. The difference in flux of each unit is within 0.02 %.

The intrinsic temperature coefficient of the ferrite material, about -0.2 % / degree, is canceled by interspersing "compensator alloy strip sheets" between the ferrite units above and below the pole tips. The compensator is an iron-nickel alloy with a low Curie temperature and therefore a permeability which depends strongly on temperature. The type MS-1A (SUMITOMO SPECIAL METALS Co., LTD) has been chosen because of larger temperature of dependence of –1.5 % / degree around 20 °C over 100 Oe. This shunts away flux in a temperature dependent manner which can be arranged to null out the temperature dependence of the ferrite. 12 strip sheets of MS-1A with 1.2 mm thick were inserted every 100.6 mm long brick and a 3 mm supporting dead space.

Figure 5 shows the flux density, its gradient at a longitudinal center and those integrated fields, measured by a 2-D field mapping with flip coil system. At center, the dipole field is 0.127 T and the quadruple field is 0.307 T/m. The error in quadruple field is kept within 1 % in required good field region +/-50 mm, but its integrated value of quadruple field has a larger gradient, sextuple component, 2.7 %. This is intrinsically caused by the difference in longitudinal leakage field at both ends due to the finite size of the pole tips. It has been comfirmed that those errors can be corrected by means of end shim correction technique with several-mm thick shims.

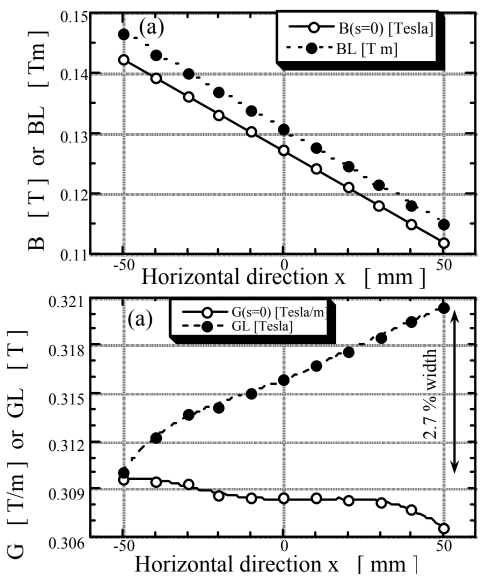

Figure 5: Horizontal profiles of measured fields: (a) *B* at longitudinal center and *BL*, (b) *G* and *GL*.

Figure 6 shows the measured results of the temperature dependence of a gap flux density (a solid line), for comparison with an equivalent dependence of the ferrite (a dotted line). The variation against temperature is +0.022 % / degree and equivalent to 1/9 magnitude of a ferrite tendency. It is a little overcompensation, but is tolerable and can be adjusted by removing one or two sheets of temperature compensator strip.

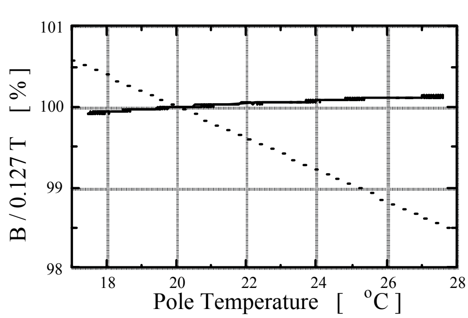

Figure 6: Measured temperature dependence of center field(solid). The dotted line indicates -0.2 % / degree.

4 SUMMARY

A test stand was constructed for the 200 kHz switching with SI-thyristors for an induction acceleration and a good performance was observed from an electrical sight. It is necessary to develop to a repetition controllable 10 kV / 662 ~ 882 kHz modulator for the upgrade of the KEK 12 GeV-PS. To find the cooling system and continuous working test are the next steps.

A prototype of permanent gradient magnet was assembled to establish a manufacturing process, to measure its magnetic flux density, its field gradient and to investigate multipole components and those correction. Dipole, quadruple fields and those integrated values at horizontal center are desirable. On the other hand, an end-effect appears evidently in the horizontal dependence of the integrated quadruple field, but it is correctable. Temperature variation was suppressed by inserting Fe-Ni alloys. This work is partly supported by the Grant-in-Aid for Scientific Research on Priority Areas "Neutrino Oscillation and Its Origin", No.12047228.

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