DEVELOPMENT AND CHARACTERIZATION OF PRE-PROTOTYPE DIPOLE MAGNETS FOR 700 MeV BOOSTER MAGNETS UP-GRADATION

K.Sreeramulu#, S. Das, P.K.Kulshreshta, Vanshree Thakur, Ashok Kumar, B. Srinivasan, Anil Kumar Mishra and S.S. Prabhu
Raja Ramanna Centre for Advanced Technology, Indore, India

Abstract

In RRCAT, the magnet up-gradation work of 700 MeV booster ring has been taken up. The booster dipole magnets are of sector type, required to be operated from 0.037 to 1.3 Tesla with a repetition rate of 1.5 Hz. The field uniformity (ΔB/B) required is $5\text{x}10^{-4}$. The effective length of the magnet is 1.887m. In order to choose suitable magnetic materials to investigate the effect of remanent field at very low excitations e.g. 0.037 T at 20 MeV, two short length (0.8 m) laminated dipole magnets with actual cross-section have been developed from two different core materials, one with 0.5mm thick silicon steel and other with 1.5mm thick low carbon steel laminations. These short length magnets have been magnetically characterized. The details of pre-prototype dipole magnet fabrication and their characterization will be discussed in this paper.

INTRODUCTION

The existing booster synchrotron (currently operates at maximum energy of 550 MeV) at RRCAT, Indore, is used as injector for both the storage rings- Indus-I (450 MeV, 61°A critical wavelength) & Indus-2 (550 MeV - 2.5 GeV, 2°A critical wavelength) and is in regular operation since 1995. The dipole magnets of booster were the first magnets built in the centre in 1992. These are the sector type laminated magnets (60^0 bending angle), epoxy glued, made from 0.35mm thick, M6 grade CRGO silicon steel punchings. The bonding between the glued laminations is weakened over the period of time and separation between them increases with the increase of magnet excitations, thereby prevents its use at 700 MeV for the injection into the Indus-2. Also, the magnetic field uniformity (ΔB/B) of the present magnets lies in the range of $1.5\text{x}10^{-3}$ (at 20 MeV) to 2.9 $\text{x}10^{-3}$ (at 700 MeV) [1]. Hence, the up-gradation work of dipole magnets has been taken up with improved magnet design and fabrication techniques. A new dipole magnet has been designed using OPERA – 3D code, for a minimum magnetic field of 0.037 T (@20 MeV) to a maximum field of 1.3 T (@700 MeV) with specified integrated uniformity (ΔB/B) of $5\text{x}10^{-4}$ within the good field region of ±40 mm (H) & ±17 mm (V) in the magnet pole gap of 52mm [2].

PRE-PROTOTYPE DEVELOPMENT

It has been observed in the existing booster dipole magnet that at very low excitations (e.g. 0.037 T at 20 MeV) the field quality in the good field zone is affected by the variation of the remanent field (ΔB/B ~1.5 x 10^{-3}).

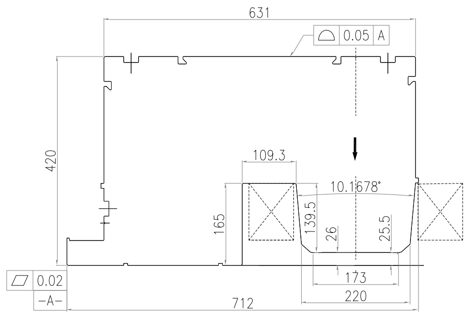

Figure 1: Half cross-section of dipole magnet in mm

To study the effect of remanent field at very low excitations and thus to take necessary modifications (if required) of the new design, two identical short length (0.80 m) pre-prototype dipole magnets with actual designed cross-section have been fabricated using two different available core materials [one with 0.5 mm thick, M36 grade CRNGO silicon (~ 2.2%) steel and other one with 1.5 mm thick low carbon (~ 0.005%) steel laminations].

Each short length magnet sector assembly (outer radius of 1.9 m & sector angle of 24°) is made from two geometrically identical half laminated core assemblies, using laser-cut laminations. Improved fabrication techniques are followed for making the magnet rigid with tight geometrical tolerances on magnet pole gap size and length. To fabricate each half laminated assembly, a rigid stacking & welding fixture is designed and fabricated for guiding & stacking the laminations. Initially, the laminations are thoroughly cleaned and stacked against reference surfaces in the fixture and then, compressed to achieve a lamination packing factor ≥ 96 %, between two thick non-magnetic stainless steel (SS316) end plates. As the core is of sector type, seven cut laminations are used in addition to full size laminations, to get the specified sector angle. For this, initially all cut laminations are stacked and glued locally with a fast curing, high strength adhesive and made the required small sector angled (0.87°**)** laminated blocks. All these small sector blocks, with full size laminations are inserted with end plates in the fixture to get the required full sector angle (24°) of each pre-prototype and ensured the geometrical accuracies of the stack before welding with pre-machined stiffener plates. Special care is taken during welding of the stiffener plates with the compressed stack for minimizing the weld distortion due to thermal gradients. The finish machining is carried out only at the matching and pole regions of the fabricated half core assemblies to

#sreeram@rrcat.gov.in

achieve the specified pole gap accuracies in the assembled magnet. The pole gap of two pre-prototype core assemblies after machining is inspected and size variation is found to within ± 40 x10^{-6} m tolerance and length of the assembled magnet is maintained to ± 0.2 x 10^{-3} m. Then, each magnet assembly is dowelled diagonally at two locations to ensure the repeatable positioning after subsequent disassembly & reassembly of two halves. Figure 2 shows the assembled magnets with ‘C’ type cross-section, having overall size of 0.710 x 0.820 x 0.800 m. The excitation coils in six pancakes (each with 10 turns) are wound with 15x15x∅10 mm OFHC square hollow copper conductor. The inter-turn insulation is provided by wrapping E- grade glass tape. The wound coils are epoxy resin vacuum impregnated & encapsulated for ground insulation. The finish weight of each magnet is 3.5 MT.

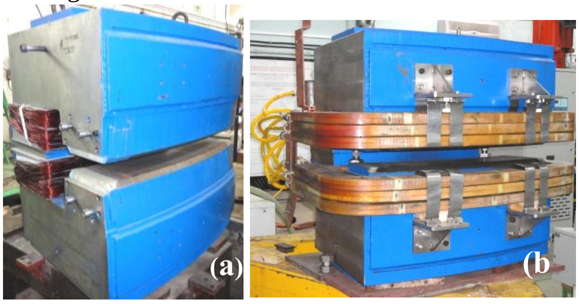

Figure 2: Pre-prototype dipole magnets (a). 0.5mm thick silicon steel laminated core (b). 1.5mm thick low carbon steel laminated core with water cooled coils

CHARACTERIZATION OF MAGNETS

DC field measurements were done using Group3 Hall probe (accuracy 0.01 %). Fig.3 shows the radial field uniformities within the good field zone of ±40 mm at different energies for the magnet made by 0.5mm thick silicon steel laminations. The measured results at 20 MeV do not agree with that of the simulated result. This is because of the fact that the simulation does not take into account the effect of remanent field variation. Once the measured variation of the remanent field (at zero current) are superimposed on the TOSCA results at 20 MeV, the agreement between the two is quite good (black line with arrow) [3]. Similarly, figure 4 compared the measured results with that obtained from the simulations for the magnet made by 1.5mm thick low carbon steel laminations. We have also carried out the magnetic measurement of the dipole magnet (made by low carbon steel) in ramped condition (at ramp rates of 2000 A/s and 3500 A/s) using search coils. The DC and AC measurements are found to be in good agreement with each other.

CONCLUSIONS

Having compared the results of pre-prototypes (CRNGO Si & low carbon steel), it can be concluded that the variation of the residual fields (at zero current) across the good field region dictates the field quality at very low

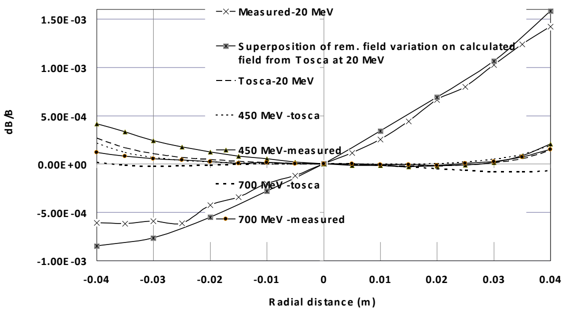

Figure 3: Comparison of measured and simulated radial field uniformities in the good field zone for CRNGO silicon steel magnet.

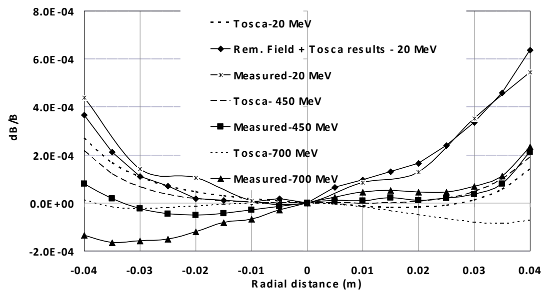

Figure 4: Comparison of measured and simulated radial field uniformities in the good field zone for low carbon steel magnet.

excitations to a great extent for a magnet made by silicon steel material than that of made by low carbon steel. The field quality of the existing booster dipole magnet (made by CRGO Si steel) at injection energy is also dominated by the variation of the remanent field. The variation of remanent field can be expressed as , $\Delta B_r = \frac{\mu_o H_c \Delta l}{g}$ where H_c is the coercivity of the material, g is the pole gap and Δl is the difference in path lengths inside the core. It appears that the variation of path lengths inside the core is higher for the above CRGO/CRNGO grade silicon steels than that of the low carbon steel.

At lower excitations (close to injection energy) radial field quality is found better in the magnet made by low carbon steel than that of made by CRNGO silicon steel. Moreover, there is scope to improve further the field quality at lower energies by adjusting the shims for a magnet made by low carbon steel.

REFERENCES

[1] A. Valecha et al, “Results of Magnetic Measurement of Booster Dipole Magnet”, Internal report, CAT/ 2003-14.

[2] S.Das et al, “Design of New Dipole Magnet for the Existing Booster Synchrotron at Raja Ramanna Centre For Advanced Technology” InPac09, http://inpac.rrcat.gov.in/downloads/inpac/index.pdf

[3] Opera-3D version 12, Vector Fields Limited, 24 Bankside, Kidlington, Oxford OX5 1JE, England.