STUDY OF VACUUM RELATED PROBLEMS DURING THE ENERGIZATION OF K-500 SUPERCONDUCTING CYCLOTRON

Md. Z.A.Naser#, U.Bhunia, J. Pradhan, J Debnath, S. Paul, M.Dutta, A. Pole, D.L.Bandopadhaya, A. Sur, C. Mallik and R.K.Bhandari

Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata-700 064, INDIA

Abstract

The K500 superconducting cyclotron main magnet has been commissioned successfully in VECC, Kolkata. During the process of energization, it has been observed that there is vacuum deterioration in the cryostat outer vacuum chamber (OVC). Detail studies have been carried out to examine the occurrence of such a situation. The electro-magnetic stress due to Lorentz force increases with current, and is more pronounced in the median plane region of cryostat having maximum number of welded joints. This could be the possible reason for the OVC vacuum degradation. The paper reports various observations on vacuum deterioration during energization. An extensive study has been carried out to understand and explain the situation.

INTRODUCTION

The K-500 Superconducting Cyclotron (SCC) main magnet consists of two superconducting coils (alpha coil and beta coil), which has been energized to different current levels for extensive magnetic field measurement. The superconducting coil inside the liquid helium chamber is suspended by nine number of support links; of which, three pulling up, three pulling down and three pulling radially out. This support system carries the whole weight of the coil and cryostat. An annular vacuum chamber, made of magnetic steel, referred as cryostat OVC, surrounds the stainless steel cryostat bobbin. Prior to cool-down of the cryostat, the force experienced on the support links is estimated theoretically, which is reported elsewhere [1] and compared with measured values. This is very crucial for the health of the support links, which is attached to the outer wall of the OVC. During higher excitations of superconducting coil, it is observed that the OVC vacuum degrades gradually. The mass spectrograph for helium leak detection (MSLD) is carried out and multiple leaks in the order of 10^{-4} mbar-lt/sec are found. Occurrence of such a situation is analysed in this paper. One of the basic reasons may be, that, during excitation a huge magnetic force develops on the OVC wall (coil tank) made of magnetic steel. This leads to a localised magnetic stress on coil tank, which is having several welded joints around the median plane. There is a possibility of mechanical failure on the defective welded joints (if any) of the coil tank at higher excitation. Another reason of failure may be due to the radial force experienced by the bobbin if the coil is off-centred with respect to surrounding iron yoke. This force propagates to the coil tank through support links.

#zamal@veccal.ernet.in

ANALYSIS

Experimental Observations

During cool-down of the superconducting coil a huge thermal force is developed as shown in figure 1 by the shrinkage of the cold mass and support links. Though the experimentally observed link force profile during cool-down matches with calculated value, there is mismatch between calculated and experimentally observed values. This is may be due to the differences of material property used during the calculation.

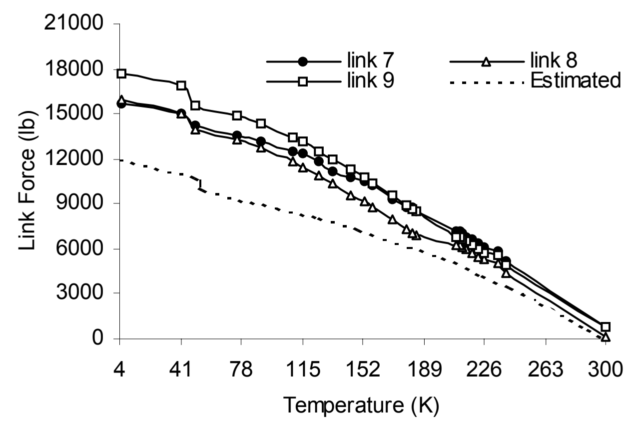

Figure 1: Support link force variation during cool-down of the superconducting coil.

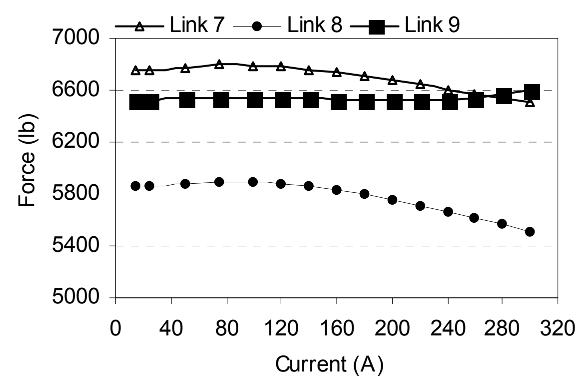

Figure 2: Support link force variation during energization of superconducting coil.

Tensile force on the radial support links decreases as the coil relaxes while energizing. The force recorded online during energization is shown in figure 2. The increase of tensile force on the radial support link indicates the centering error of the assembly.

It is observed that the OVC vacuum deteriorates with current as shown in figure 3. It is interesting to note that the degradation of OVC vacuum is dependent mainly on the current in alpha coil, which is nearer to the median plane. Being nearer to median plane, alpha coil has more contribution of magnetic field than beta coil, in the median plane region of OVC.

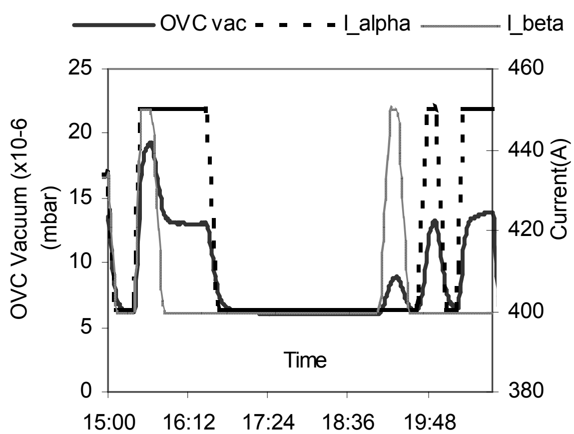

Figure 3: Variation of OVC pressure with alpha and beta coil current.

MSLD is carried out on the outer wall of the OVC with and without the current in the coils and existence of multiple real leaks is observed near the median plane. Figure 4 shows the temporal variation of the relative leak rates as well as OVC vacuum.

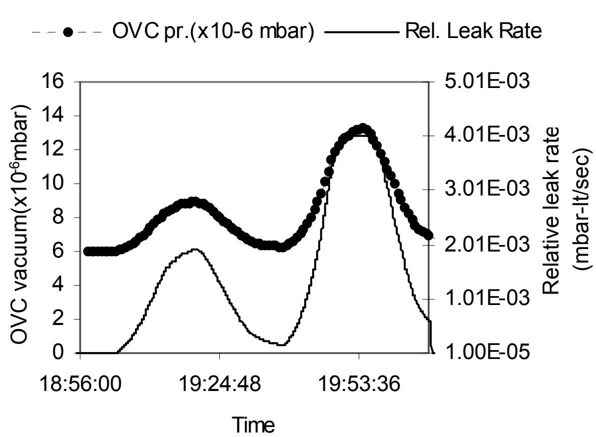

Figure 4: Temporal variation of leak rates and vacuum

The oscillating behaviour of the OVC vacuum with time may be due to the periodic bursting of condensed air molecules on various layers of multilayer insulation (MLI) as well as other cold surfaces inside the cryostat.

Theoretical Study

To analyze the fact that the OVC vacuum relates with the coil current, a 2-D model of the main magnet of K-500 SCC with iron yoke is simulated by Multiphysics ANSYS software. The magnetic stress near the median plane of the outer wall of coil tank is calculated at different coil excitations. Figure 5 shows the variation of the magnetic stress with the current level, and is fitted parabolically as

$$(S_X - 228.05) = -0.005(I + 145.57)^2 \quad (1)$$

$$(S_Z - 232.67) = -0.0093(I + 101.16)^2 \quad (2)$$

Here, S_Z S_X and I are axial stress (psi), radial stress (psi) and coil current (A) respectively.

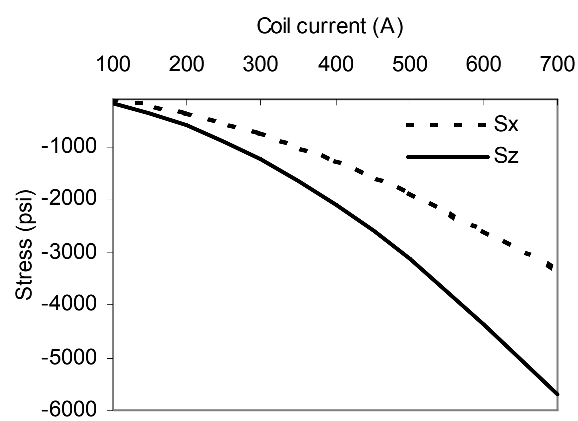

Figure 5: Magnetic stresses on the outer wall of OVC around the median plane at different coil excitations.

The magnetic stress at highest current level, as shown in the plot above is much lower than the yield strength of the carbon steel. But if there is any point defect especially in the welded part of the material, then there may be chance of mechanical failure due to the propagation of the defect.

The main magnet coil is placed at the center of the surrounding yoke with an accuracy of 0.1 mm. This ensures the magnetic center of coil and surrounding iron yoke aligned. If there is any centering error there will be a huge force on the coil that transfers to the OVC wall via support links. The radial unbalanced force is generated by $J_\theta \times B_z$ interaction and is directed radially. The force is directly related to the gradient of z component of magnetic field at the coil region produced by the magnetic iron. The field gradient is calculated from ANSYS model.

The lines of force obtained from ANSYS model is shown in figure 6. For an infinitesimally small radial offset Δr of the coil w.r.t the iron assembly, the radial force developed is approximated as [3]

$$F \cong 4\pi\Delta r \int_r \int_z J \frac{\partial Bz[r,z]}{\partial r} r^2 drdz \tag{3}$$

The unstable force developed due to as small as 1 mil radial coil shift with respect to surrounding iron yoke at various excitations is calculated and shown in figure 7. The axial force developed due to vertical off-center of the coil median plane with respect to magnetic median plane is stable and is directed opposite to the direction of offset. Therefore, the centering of the coil by careful adjustment of support bolts in each link is necessary to minimize the magnetic force on the coil as well as outer vacuum chamber.

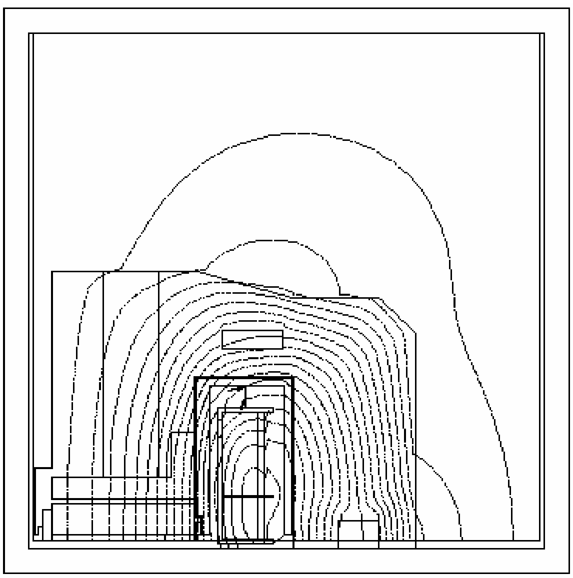

Figure 6: Magnetic lines of forces by ANSYS.

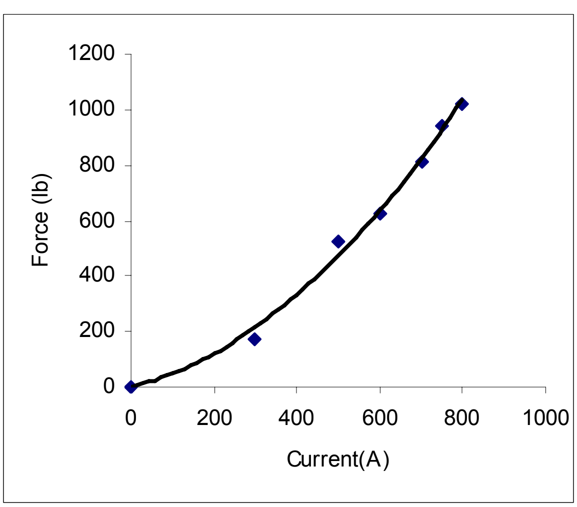

Figure 7: Radial unbalanced force w.r.t. current for 1 mil off-center.

CONCLUSIONS

Analysis establishes the fact that there is correlation between OVC vacuum and current, provided there is mechanical defect, void, or existence of any real leak on the wall of the OVC. It is extremely difficult to find out the real leak of OVC because of the non-accessibility in the assembly state of the K-500 Superconducting Cyclotron. Leaks have been identified carefully and repaired permanently by welding. Overall MSLD leak test (~ 10^{-8} torr-litre/sec) has been performed and it has been measured that OVC can now sustain very good vacuum level (~ 10^{-5} mbar). This will further improve during cryo-pumping by the cold surface in OVC. The radial off-centering force estimation suggests that the slight movement of the coil is very harmful to the OVC. During cool-down and energization the link forces are adjusted to keep the tensile forces much lower than the yield strength of the support link materials (glass epoxy). The abrupt change of the support link force during mechanical adjustment at higher excitation is very dangerous to the health of support link and OVC wall as well.

ACKNOWLEDGEMENT

Authors express their sincere gratitude to all colleagues who has directly or indirectly involved for successful completion of K-500 main magnet energization.

REFERENCES

[1] U. Bhunia et al, “Thermal Stress in the Support Link of K500 Superconducting Cyclotron Coil during Cool-down”, INPAC’05, VECC, March 2005, p. 509.

[2] J. Pradhan et al, “Studies of Magnetic Forces during the Energisation of K-500 Superconducting Magnet”, INPAC’05, VECC, March 2005,p.353.

[3] Iwasa, “Case Studies in Superconducting Magnets Design and Operational,” Plenum Press, New York, 1994.