OPERATIONAL EXPERIENCE OF SUPERCONDUCTING CYCLOTRON MAGNET AT VECC, KOLKATA

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Abstract

The Kolkata Superconducting cyclotron magnet has been operational in the Centre since last few years and enabled us to extensively map magnetic fields over a year covering the operating range of the machine and successful commissioning of internal beam. The magnet cryostat coupled with the liquid helium refrigerator performs satisfactorily with moderate currents (<550A) in both the coils. The superconducting coil did not undergo any training and over the years has not suffered from any quench. Author would share the experience and difficulties of enhanced overall heat load to the liquid helium refrigerator at higher excitations of coils. This creates instability in the operation of liquid helium refrigerator and finally leads to slow dump. Rigorous study has been carried out in this regard to understand the problems and operational logic of liquid helium refrigerator has been modified accordingly to alleviate from. Some other measures have also been taken from cryostat and cryogenic distribution point of view in order to reduce the heat load at higher excitations, optimize the current lead flow, etc.

INTRODUCTION

Variable energy cyclotron centre, Kolkata is successfully operating its superconducting cyclotron main magnet since 2006 that enables us to successfully map magnetic fields over a year covering the operating range of machine and successful commissioning of internal beam. 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. An annular vacuum chamber, made of magnetic steel, referred as cryostat OVC, surrounds the stainless steel cryostat bobbin. In the following sections, several operational problems of cyclotron magnet encountered over the past few years have been explained.

EXPERIMENTAL OBSERVATIONS

OVC Vacuum during Liquid Helium Filling up

Moisture level in the cryostat was brought down to 20ppm before starting up of cool down process. During the process of cool-down tension in radial support link increases gradually. The positional adjustment is necessary, if the force approaches a maximum allowable level by tightening/loosening the support bolts attached with each link.

It was found that helium leakage would change as the cryostat was filled with liquid helium. Correlating the helium leakage rate with the liquid helium height of cryostat has allowed vertical location of leakage to be found as shown in figure 1.

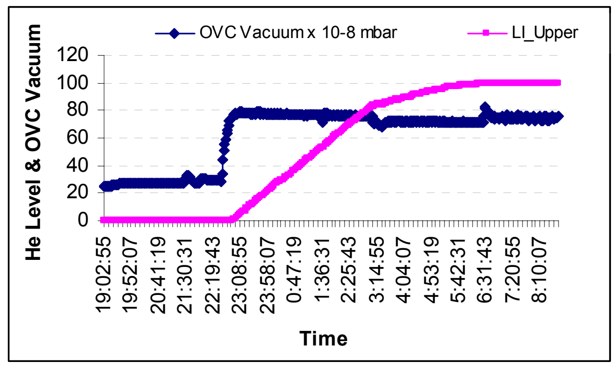

Figure 1: OVC vacuum during liquid helium filling up

Due to inaccessibility of the location of leak (~ low 10^{-4} mbar-lt/s) inside the cryostat, it was not feasible to repair it. However, there are several very small leaks found in the outer median plane region of cryostat and repaired those successfully.

OVC Vacuum during Energization

It is observed that the OVC vacuum deteriorates with current as shown in figure 2. 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. In this regard, detail study has been carried out [1]. Being nearer to median plane, alpha coil has more contribution of magnetic field than beta coil, in the median plane region of OVC. For alpha current of 600 A and beta current of 400 A, OVC vacuum degrades to 3.0E-4 mbar.

Additional pumping module of pumping speed for He ~300 lt/s has been installed with the OVC annular space to improve the vacuum to low 10^{-5} mbar. In addition, observations are kept on cryogenic transfer line if any frostings occur over it and annular space is evacuated to a vacuum level better than 1E-6 mbar.

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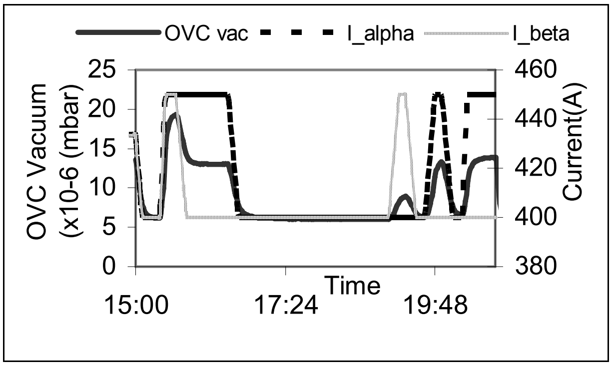

Figure 2: Variation of OVC pressure with coil current

Instability of Helium Refrigerator Expander Control Loop

Out of all control loops, expander control loop is very vital in the control of the helium liquefier performance. The control loop was affected partly due to temperature sensor problem and partly due to improper programming also. When we were coupling the plant with the cryostat with full current in the coils of the superconducting magnet, the expanders were unable to provide rated cooling. We were controlling the expander control valve mostly in manual mode by seeing the pressure in the cold expander outlet (LP), liquid helium level in the Dewar and pressure in the compressor outlet (HP) etc. This was troublesome and prone to error. So we were unable to handle even 100 W @ 4.5 K load in the cryostat and transfer lines.

The transients created during current ramping up or down and cryostat return valve operation was such that, it was creating a problem of pressure swing in HP and LP line of compressor. Sometimes even it was tripping by crossing the alarm limits. We were bound to have less opening of expander control valve to get rid of compressor tripping problem. Less opening of expander control valve was leading to less refrigeration power. So some modifications in the expander control loop had been implemented [2] to take care of the scenario previously done in manual mode.

Parameters	Old program	New program
Set point	14.00# (Bar abs.)	3000*X Attenuators(rps)
Feed back	Compressor high pressure	Warm expander speed
Prop. Band	6.5%	400 %
Integral time	1 min	15 sec

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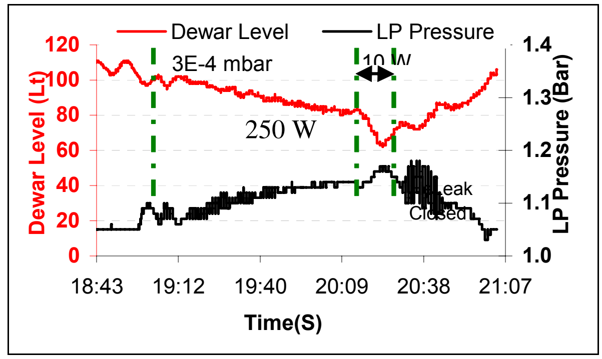

Figure 3: Heat Load study for OVC maintained at 3.0E-4 mbar.

Initially the expander control was based on compressor high pressure feed back. As the compressor high pressure was not changing according to cycle performance, the expander control valve was more or less constantly opened at a fixed value. So it was producing a constant cold power irrespective of the cycle refrigeration load. This was the root cause for instability in the system. Expander's speeds are the quick indication of change in the system thermodynamics. Therefore expander valve control operation has been modified to operate as per the warm expander speed feed back and the refrigerator is capable to handle even 3E-4 mbar vacuum in annular space (≅ 250 W @ 4.5 K) as shown in figure 3.

Optimization of Current Lead Helium Flow

Three vapour-cooled AMI current leads are used for the energization of the main magnet coil of K 500 cyclotron in VECC, Kolkata. Optimum helium mass flow rate at different operating currents, voltage developed across the current leads has been investigated since data were not available from vendors. Slow dump interlocks has been put to the power supply w.r.t. lead voltage drop of 100 mV.

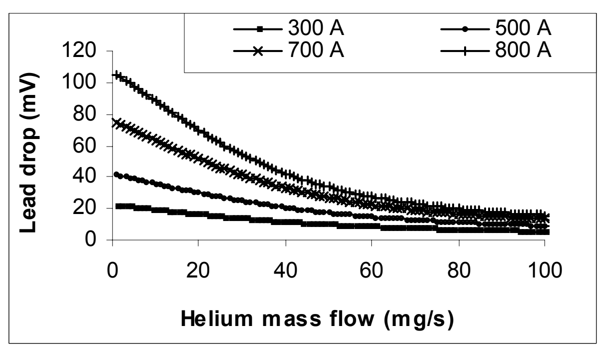

Figure 4: Simulated lead voltage drop for various excitations

Current lead voltage drop are also measured and compared with the theoretical study for 300 A of current in both the coils as shown in figure 5.

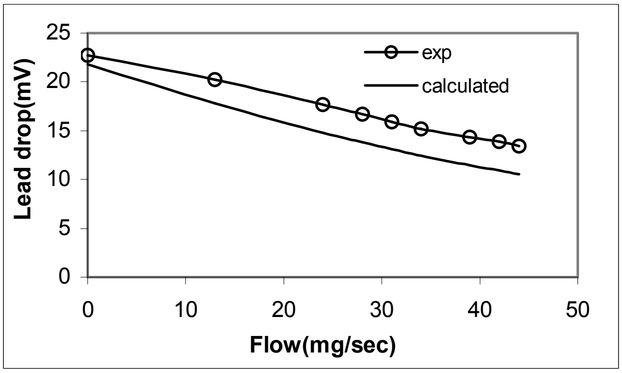

Figure 5: Comparison of lead voltage drop with experimental curve

Slow & Fast Dump Scenario

Each coil is protected by slow and fast dump resistor against any unusual scenario like low helium level in cryostat, excess pressure in cryostat, detoriation of OVC vacuum over a set value, excess lead voltage drop, etc. In several occasions, fast and slow dump occurred due to failure of preset interlocks value though there was no real quench like phenomena developed.

CONCLUSION

Over the past few years, we have encountered several problems corresponding to various subsystems and solved most of the difficulties such as extra heat load to cryostat, instability to helium refrigerator, etc. The superconducting cyclotron magnet is now operating quiet smoothly for ion beam acceleration.

ACKNOWLEDGEMENT

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