RECENT EXPERIENCE ON TROUBLE SHOOTING OF 4.4 K REFRIGERATOR DURING LONG RUN OF LINAC

Anup Choudhury, J Chacko, S Kar, M Kumar, S Babu, J Antony, Raj Kumar & T S Datta
Inter University Accelarator Centre, New Delhi – 110067

Abstract

The existing helium plant of capacity 500watt @ 4.4K has been in use at IUAC for several years primarily to cool down and provide refrigeration to the LINAC cryo module [1] consisting of niobium cavities. The refrigerator uses two reciprocating piston type expanders working at ~60K and ~20K respectively, and JT valve at the third stage of cooling. Prior to the recent long run, started in July 2010 we observed a few problems with the machine such as long initial cooldown time, loss of refrigeration capacity and very high LN_2 consumption per litre of LHe production.

These issues needed urgent attention. The problems were identified through a systematic approach and they were solved one by one. The paper highlights these problems vis a vis the cause and the subsequent remedy employed.

INTRODUCTION

A helium refrigerator (piston engine type) with a cooling capacity of 500 W @ 4.4 K has been in use at this centre since1997. For the first few years the refrigerator ran in liquefier mode primarily to test the RF niobium cavity resonators off line in a dedicated test cryostat and various other cryogenic tests. First of three LINAC modules each with 8 Nb-cavities and a superconducting magnet was commissioned in 2002 and the machine started working online to cool the LINAC cryo-module, Rebuncher and Buncher cryostat in refrigeration mode. This module has been serving the users community well for last 6 years and so has been the refrigerator. Before the last user experiment run in July 2010, a number of problems cropped up almost simultaneously which warranted immediate attention and called for the solution of the problems. Apart from other smaller issues the main problems were related to the long cool down time, high usage of liquid nitrogen and lastly the deterioration of the cooling capacity of the machine. Problems were identified and resolved through suitable changes in operational procedure and the changes made to the compressor and engine control system for efficient operation.

COOL DOWN TIME

During the initial years of operation the cooldown time of the machine from 300-4.5 K used to be ~11-12 hrs. In later years this cooldown time started increasing and we also observed some unusual behaviour of the machine during this cooldown period. Closer scrutiny of the problems, however, was not taken as the liquefaction rate of the machine did not go down as much even though the cooldown time had increased. It was also observed that during the prolonged cooldown period the dewar temperature used to be ~25-30K (Fig-1) for very long time. This temperature stagnation conjectured at possible hydrogen contamination in the vacuum jacket of transfer line connecting dewar and the cold box. A closer look at this 2 core transfer line revealed that this line was slightly colder than its surrounding and also there was some small frosting at the vacuum jacket bends. All these observations prompted us to believe that there was indeed vacuum degradation due to hydrogen desorption at the transfer line after ~13 years of operation.

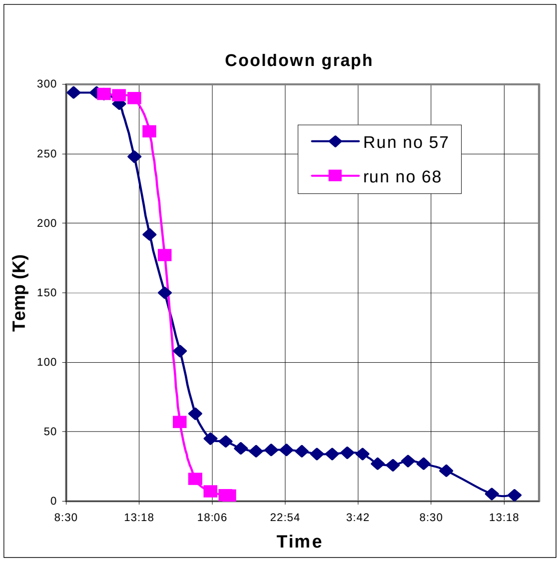

Figure 1: Cooldown comparison graph.

The transfer line was evacuated for two weeks with continuous heating of the vacuum jacket and ultimate vacuum of <5x10^{-6} torr was obtained. This vacuum conditioning reduced the cooldown time drastically from 30 hrs to 12 hrs. Figure-1 gives a comparative assessment of the time improvement in the cooldown time after the vacuum conditioning. The cooldown time was further improved by an additional 2 hrs by optimising the helium gas flow rates though different channels.

HIGH LN_2 CONSUMPTION

During one of the early 2010 runs it was observed that the liquid nitrogen consumption has shot up dramatically to almost double the quantity compared to earlier stable runs and also we could see the whole of the return line (~80 mts long) to the compressor suction completely frosted (Fig-2) during the liquid production phase of the run. The problem was identified to be a blockage of one of the 6 lines in heat exchanger 1 (HX-1) in the discharge side resulting in a lower surface area available for the cold return gas to exchange all the cold enthalpy. The discharge line was therefore heated and purged with dry nitrogen gas to drive away the water in the line. But the problem of excess LN_2 consumption persisted along with frosting of the entire suction line. Then a dew point measurement check of the discharge lines showed a lot of moisture (-30 degC) in the charcoal beds (80K and 20K) and GMS bed in the compressor room. Such high level of moisture soaking in all the three charcoal beds pointed to a moisture contaminated helium gas charge earlier, and was blocking HX-1 slowly and repeatedly during operational cooldown.

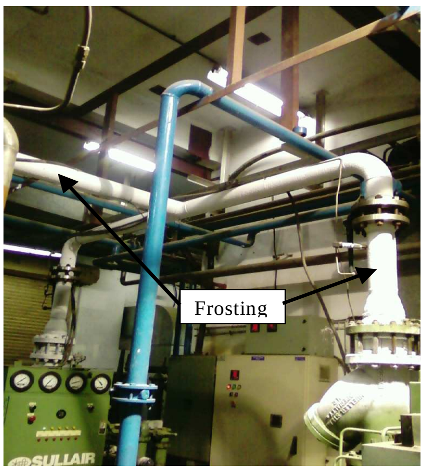

Figure 2: Frosting in suction line.

To solve the problems all the three charcoal beds and process lines inside cold box were purged with hot (~100^{o}C) dry pure nitrogen from in-house LN_2 plant. The drying process ended after 10 days when the dew point of the outlet gas was better than –70 deg C. Then the whole of the helium circuit lines were thoroughly pumped and purged with dry helium from the tanks.

LOSS OF REFRIGERATION CAPACITY

During the liquefaction runs of 2010 we observed that the outlet temperature of the cold engine was higher than its normal operational value (signifying a drop in efficiency of expander and therefore loss of refrigeration). Also we noticed more than normal frosting on the neck of the piston rod outside. The loss of refrigeration was thought to be to gas bypass through valves and so the engine assembly was opened.

i) After opening the cold engine assembly one spring loaded helicoflex ® seal in the high pressure inlet line was found to be loose and the connecting bellow flexed to a great extent. This leak was effectively bypassing the gas from discharge to suction without the gas doing any work on the piston. The seal was changed along with the bottom assembly with a new bellow.

ii) During the assembly of the new lower block of cold engine the inlet and outlet line valves were found to be leaking and so these had to be lapped again to proper shapes before final assembly.

After these rectifications LINAC operations resumed in early 2010. The machine was run in refrigeration mode to cool all the three cryostats, Buncher Cryostat (BC), LINAC and the Rebuncher Cryostat (RBC) along with the whole distribution line. The cooldown of the entire system was smooth and the system ran for almost 20days. Then RBC cryostat had to be switched off as machine was producing less power. After 40 days of operation, LINAC cavities had to be put off one by one for dearth of cooling power from the machine and finally the LINAC operation had to be stopped after 50days. During these 50 days of operations the cold expander speed had to be increased significantly (135rpm-210rpm) to augment the gradual loss of refrigeration. On further analysis of the loss of refrigeration data we could clearly see that there was some trouble in the teflon lined piston and SS cylinder combination clearance and so the engine was reopened after warm up again.

On opening it was seen that the piston rod had bent and the piston cylinder teflon liner got damaged due to this off centre operation. This erosion of the liner caused the bypass of the gas resulting in loss of refrigeration. The dead volume inside the cylinder had also increased which was reducing the refrigeration capacity. As a corrective action the piston cylinder and connecting shaft was replaced with a new one.

Thus we were able to identify the problems responsible for the degradation of the refrigeration power of the machine and fix them. After the correction the machine started performing well and we were able to achieve a refrigeration capacity of 350 watt @ 4.4K.

CONCLUSION

A unique set of problems were encountered in the liquid helium machine during last LINAC run. The machine was barely producing 130-135 watt @ 4.4K (measured after isolating the LINAC from the LHe plant during LINAC run). All the problems were identified and attended to successfully. After these corrective actions a capacity test was done and we could establish the old tested refrigeration capacity of 350-360 watt.

Apart from these problems there were also other minor issues such as non functioning of LN_2 controller of the machine, the engine controller replacement, engine top heating controller etc. All these problems were solved successfully. It is worth mentioning that these problems were solved despite having no support from the manufacturer.

REFERENCES

[1] T.S. Datta et.al., “Superconductivity & Cryogenics for Linear Accelerator Programme at IUAC, New Delhi” Cryogenics, Vol. 49 (6), p 243. 2009