EVALUATION STUDY OF CRYOGEN DISTRIBUTION IN TIFR-BARC SUPERCONDUCTING LINEAR ACCELERATOR

Prashant Singh, Department of Mechanical Engineering, NIT Rourkela, India
S.S.Jangam[#], R.G.Pillay, Pelletron-LINAC Facility, TIFR, Mumbai, India

Abstract

The superconducting LINAC booster, indigenously developed to boost the energy of the heavy ion beams from the 14 MV Pelletron accelerator at TIFR, Mumbai, has been fully operational since July 2007. The LINAC consists of seven modular cryostats, each housing four lead plated quarter wave resonators. A versatile and efficient cryogen distribution system has been designed and fabricated to adapt to the modular structure of the LINAC, and deliver both liquid helium and liquid nitrogen to the cryostats. Cryogenic processes can be characterized by a high degree of material and energy integration, complex process flow sheets, small driving forces for heat exchange and for flow, tight operational requirements and often very high product purities. Hence it is necessary to understand the process and control parameters for such a large system. The pressure drop in the helium distribution line is calculated to estimate the loss in the refrigeration capacity due to the helium fluid flow in the system. The heat load calculations were done to estimate the theoretical values using heat and mass transfer principles. Different correlations and models are used in the calculation of friction factor and pressure drop. Homogeneous Flow model gives good estimation in the case of helium.

INTRODUCTION

The TIFR-BARC superconducting heavy-ion linear accelerator serves as a booster to the heavy ion beams delivered by the 14 MV Pelletron Tandem Accelerator. The LINAC booster consists of seven accelerating module cryostats and one superbuncher cryostat [1]. Each module is a liquid helium cryostat housing four lead coated copper quarter wave resonators which are superconducting at temperature below T_C (Pb) = 7.2 K. The resonators are operated at liquid helium temperature (~4.2 K) in order to use the superconducting properties of lead for the generation of high accelerating electric fields with low RF power dissipation in the cavities. An efficient cryogenic system consisting of a refrigerator to produce the required cryogen, cryostats to house the accelerating structure, distribution system for transferring cryogens to the cryostat and the remote control system is required for the stable operation of the LINAC.

CRYOGENIC SYSTEM

The heart of the cryogenic system for the heavy ion superconducting LINAC booster is a custom-built liquid helium refrigerator Linde TCF50S. This is of modern design based on the modified Claude cycle with two turbo-expanders in series. The Refrigerator is rated for 300 W at 4.5 K with a dual JT (Joule-Thomson valve) at the final cooling stage, which allows simultaneous connections to the cryogenic loads (the LINAC module cryostats) and to a liquid helium storage Dewar (1000 l). The two-phase helium at 4.5 K produced at the JT stage in the refrigerator is delivered to the cryostats through a cryogen distribution system. The cryogen distribution system for the LINAC is designed to deliver both liquid helium and liquid nitrogen to the cryostats. Two phase flow from cold box is fed at the final JT valve to the main junction box. Trunk line consists of four individual lines which carry liquid helium and liquid nitrogen and the return boiled off gases. Junction boxes are the remote filling stations for the cryostats with each box serving two modules. The 3.5 m long vacuum jacketed triaxial transfer tube transports cryogens from the junction box to the cryostat. The innermost pipe supplies the liquid and is surrounded by the return gas. The helium transfer tube at each cryostat acts as remote JT. The helium vessel receives two phase flow of helium via the tri-axial transfer tube. The phase separation is achieved in the individual cryostats and the cold (4.5 K) helium gas is returned, by the distribution system, back to the helium refrigerator. The four quarter wave cavities inside each cryostat are gravity-fed from a horizontally mounted liquid helium vessel. The total mass at 4.5 K in each of the modules is close to 250 kg. The Figure 1 shows scheme of Cryogen distribution of LINAC

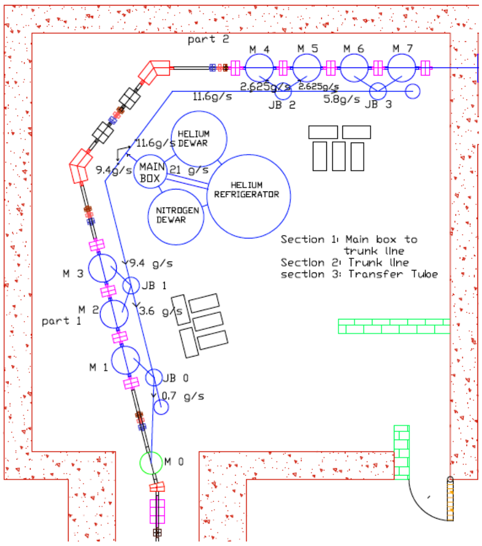

Figure1: Schematic of LINAC showing Cryogen distribution line

---

#santosh.tifr@gmail.com

Pressure Drop in Cryogenic System

The pressure drop is calculated for the helium distribution system for the Superconducting LINAC to estimate the loss in the refrigeration capacity due to the helium fluid flow in the system. Pressure drop is the result of frictional drag on the fluid as it flows through the pipe. The two phase flow is always encountered in cryogenic liquid transfer systems due to the presence of heat leak and quality factor of liquefaction. For low quality flow (small mass fraction of vapour, or bubble flow) the pressure drop may be estimated by the homogeneous flow model, in which appropriate average fluid properties (density and viscosity) are used in the single phase correlations. The homogeneous flow model is valid for two phase helium over the entire range of fluid qualities. The two phase helium (quality factor x=0.25) is produced by the TCF 50S cold box and is delivered at the rate of 21 g/s to the distribution system at the Main box. P_i (i =0 to 7) are the pressures at cryostat and V_i (i=0 to 7) are the mass attenuation factors to ensure the equal mass flow rates in the individual cryostats.

Table 1: Pressure and Valve attenuation Factors

Pressure in bara							
P_0	P_1	P_2	P_3	P_4	P_5	P_6	P_7
1.361	1.365	1.365	1.365	1.367	1.367	1.368	1.368
Valve mass attenuation factor							
V_0	V_1	V_2	V_3	V_4	V_5	V_6	V_7
0.04	0.10	0.10	0.10	0.22	0.22	1.00	1.00

V_7=1.0(fully open), P_R=1.20 bara, P_S= 1.51 bara

Heat Load in Cryogenic System

The proper estimate of the heat load on the liquid helium is required so that appropriate measures can be taken to reduce the dissipation of heat to minimum possible value without affecting the efficiency of the system. Heat dissipation takes place in all the sections of pipes, junction boxes, transfer tubes and cryostats. In cryogenic system major causes of heat load are conduction due to supports and radiation from surroundings at higher temperatures and due to a continuous frictional drag of the liquid helium which results in heat dissipation. The loss in refrigeration capacity due to frictional drag is calculated using energy conservation. The mass energy balance across Dewar gives us the loss in plants' refrigeration capacity when operated at elevated pressures. Calculating the upper limit of the heat load by assuming the supply pressure 1.7 bara and return pressure 1.2 bara, we get, Heat load = 267.67 W. This is the overall heat load which is divided into heat load due to conduction and radiation from the surroundings, heat energy produced by the frictional pressure drop and the rest load is utilized in the refrigeration.

Table 2: The cryogenic Heat Load for LINAC

	Estimated Heat Load (W)		**Heat Load**
	Phase I	Phase II	
The deviation of operating point from the rated value	----	----	10W
Frictional pressure drop losses	----	----	32W
Helium Dewar	6 W		6 W
Distribution system	16 W	16 W	32W
Transfer tube and cryostat, 12W each	4X12W=48W	4X12W=48W	96W
QWR @6W each, Superbuncher @4W	12x6W=72W 1x4W =4W	16x6W=96W	172W
Total (Phase I + II)	306 W		348W

DISCUSSIONS AND CONCLUSION

For equal flow in all module cryostats, the valve openings vary over a wide range (0.1 to 1.0). This can be attributed to the asymmetry of distribution between the two parts of the LINAC. Very small pressures changes (~10 mbar) in the supply lines, significantly affect the valve openings.

The heat load due to the different sections and parts of LINAC is 134 W which is approximately equal to that found in earlier papers. The discrepancy found in the estimated values and the observed values are attributed to the frictional losses (pressure drop) in distribution lines and the deviation of operating point from the rated T-s diagram of refrigerator. The frictional pressure drop losses are about 32 W. Hence available capacity is only 268 W. The rated capacity reduces by 10 W when operated at elevated pressure at second J-T exit. The available capacity reduces to 258 W. Thus available refrigeration capacity for the RF load is only 124 W and not sufficient. Hence we operate the refrigerator in the LN_2 precooling mode which has its limitation when long term operation is required. Hence we have considered upgrading the existing plant with higher mass flow rate. Also modifications in distribution line are suggested to reduce the losses due to frictional pressure drop. The analysis is required to optimize the operating conditions and improve thermodynamic parameters and capacity of the plant.

REFERENCES

[1] P.B.Patil, et al., “The cryogenic system for the TIFR-BARC superconducting LINAC booster”, InPAC’07, February 2007.

[2] S.S.Jangam, et al., “Improvements to the Cryogenics System for the TIFR-BARC Superconducting LINAC Booster”, InPAC’09, February 2009.

[3] R.F. Barron, “Cryogenic Heat Transfer”, Taylor and Francis, 1999.

[4] Vandana Nanal, et al., “Operational Experience of the Superconducting LINAC booster at Mumbai”, Proceedings of HIAT09, Venice, Italy, 2009.