COOLING OF HIGH PRESSURE INSULATING GAS FOR 3 MeV DC ACCELERATOR : AN ALTERNATE APPROACH

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3 MeV Accelerator is working inside the 'Electron Beam Centre' (EBC) building at Kharghar, Navi Mumbai. Generally in DC and Pelletron accelerators Nitrogen/SF_6 gas is taken out from accelerator tank and it is cooled by separate heat exchanger and blower unit outside the accelerator tank. In our alternate approach we have designed fan/blower to work under high pressure inside accelerator tank. Fans are designed to work in high pressure SF_6 environment at 7 bar absolute pressure with 42 kg/m³ SF_6 gas density. Fan through air over radiator type finned tube heat exchanger, installed inside accelerator tank. Fan speeds are controlled through variable frequency drive. Two numbers of such assemblies are fabricated, installed and tested in Nitrogen and SF_6 gas environment at different pressure and variable fan speed. Performances are recorded and plotted in graphical form. These cooling systems are shown excellent performance in last five years. Paper will discuss about design of cooling system, cooling calculation of fan, fabrication of fan and heat exchanger, 5 TR chiller unit, variable frequency drive, fan performance etc.

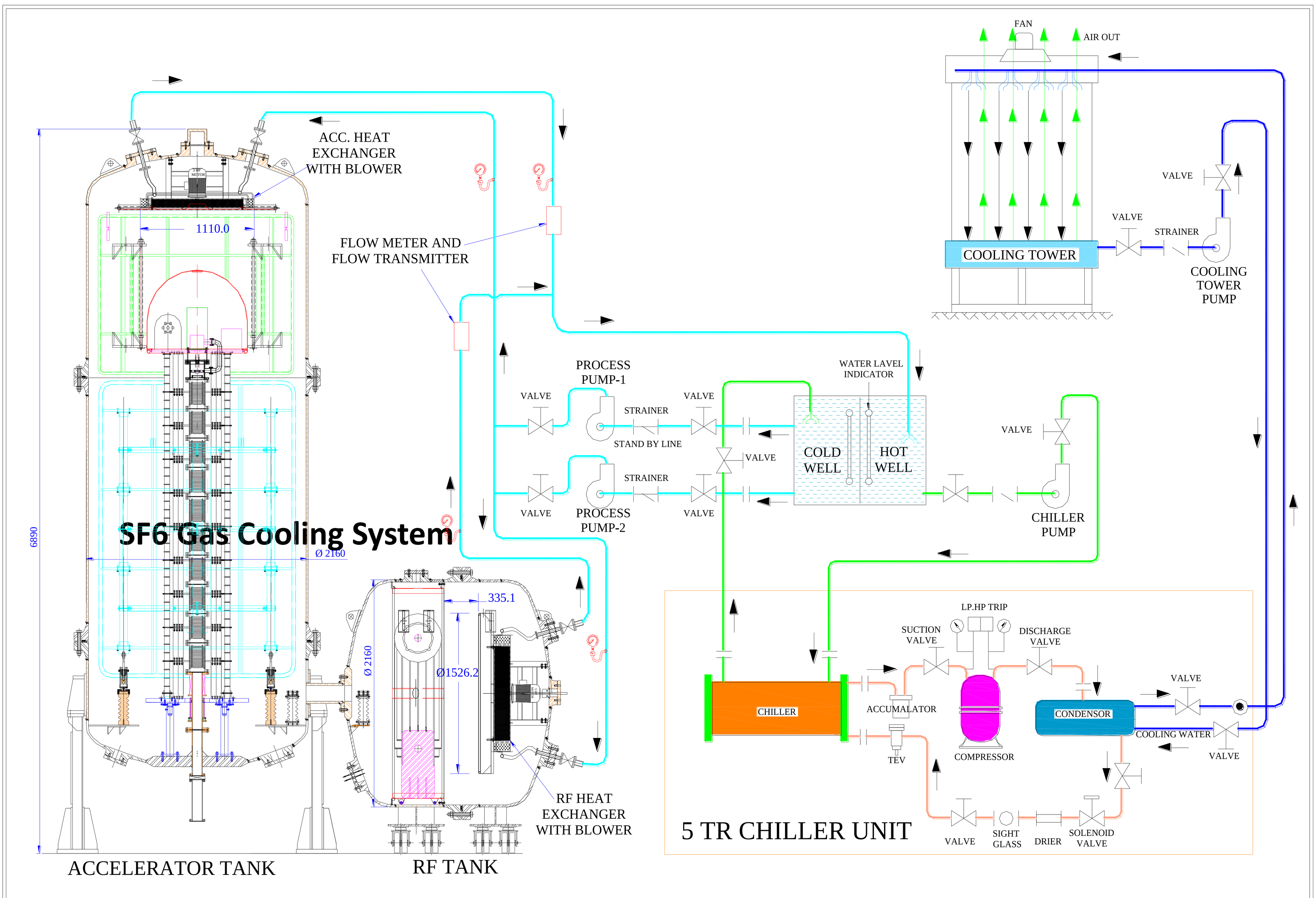
INTRODUCTION

3 MeV Accelerator is an electrostatic accelerator in which terminal is floating at a voltage of 3 MV and the accelerator tank is at ground potential. From voltage gradient point of view there is two geometries, coaxial cylindrical and spherical geometry. Design calculations show that SF_6 is the most suitable medium for insulation and cooling purpose. Apart from excellent electrical properties, SF_6 has good chemical stability, thermal properties and nontoxic. The Accelerator tank is the main body of the Accelerator, which will house HV multiplier columns, RF electrodes, corona shields, HV terminals, electron gun, accelerating tubes, heat exchangers along with blower, RF transformer etc. All of high voltage components require SF_6 gas insulation and efficient cooling. Hence there is a need of SF_6 gas and its cooling system. Operating pressure of SF_6 gas inside the accelerator tank is 6 bar(g). On line dew point measurement system is connected in accelerator tank. SF6 gas handling system not discussed in this paper.

DESIGN OF SF₆ GAS COOLING SYSTEM

The Aim of SF_6 gas cooling system is to cool SF_6 gas inside accelerator and RF transformer tanks with the help of water-SF_6 gas heat exchange process. This system is mainly comprises of 1.5" and 1" SS pipe line, radiator type heat exchanger and blower combination, 5 TR chiller unit, cooling tower, pressure transmitter, temperature sensors, safety interlocks, flow meter, flow transmitter, Variable frequency drive, pressure gauges and other instrumentation.

The blower has been designed and commissioned to achieve desired heat transfer under 6 bar(g) with 42 kg/m³ density of SF_6 gas. Standard high pressure finned tube bundle with header have been selected as per the area available inside the accelerator tank. Heat exchanger assembly is made of such four numbers of bundles and makes an enclosure of size 800 x 800 x 100 mm (Figure). Blower is fabricated from ASTM A 240 Gr 304L stainless steel plates and it is assembled inside this enclosure and throw SF_6 gas centrifugally outward direction. Two sets of heat exchanger and blower combination along with 2 and 3 HP motors has been installed and tested for desired flow rate, pressure drop and motor current/wattage (table). Blower has dynamically balanced to minimize the vibration.



SCHEMATIC OF PROCESS LAYOUT OF SF₆ GAS COOLING SYSTEM

COOLING CALCULATIONS

RF Transformer which is having a maximum heat load of 8 kW is maintained within 45⁰Celsius temperature limit. It was estimated that a total water flow rate is 60 lpm of chilled water at 24⁰C is required to remove 8 kW heat. Water is circulated through the heat exchanger for cooling of transformer/SF_6 inside the RF tank. Similarly other accelerator tank components having a maximum heat load of 4 kW requires a water flow rate is 35 lpm of chilled water at 24⁰C. Working temperature kept 22-24⁰C to avoid condensation. 5 TR chiller unit is designed for chilled water of 110 lpm at 22ºC.

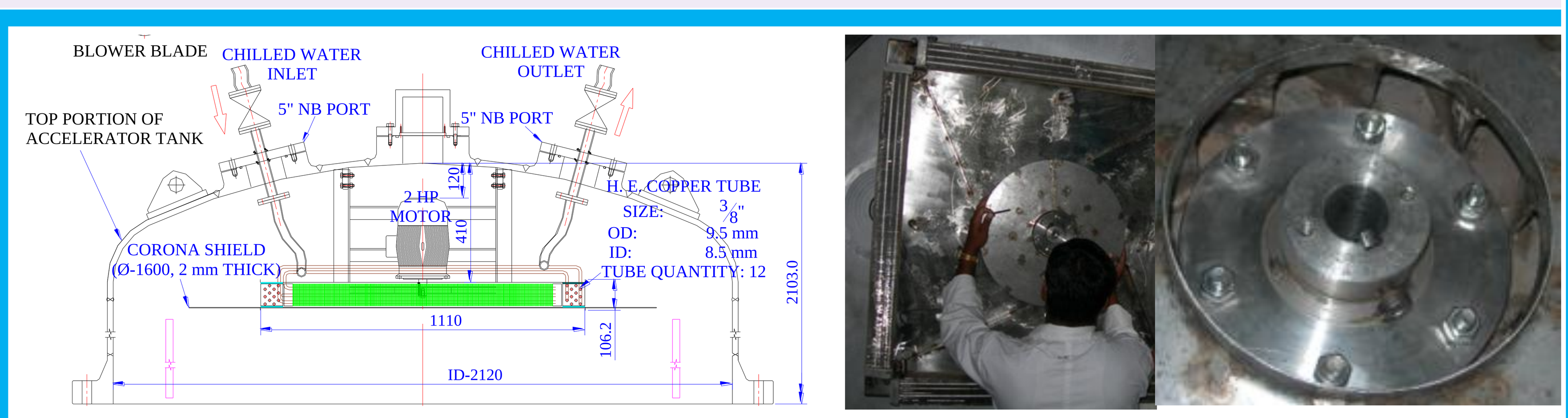
Heat transfer calculations are carried out to find out heat transfer coefficient of chiller water side and sf6 gas side of heat exchanger. Standard finned tube radiator type tube bundles are selected as per space constraint. Staggered geometry used to calculate flow across Banks of tubes as per figure-3. A design calculation for proper surface area of fin tubes and convective heat transfer coefficient in SF_6 environment at a pressure of 6 bar(g) for each bundle have been done.

A classical expression for computing the local Nusselt number for fully developed turbulent flow in a smooth circular tube the Dittus-Boelter equation

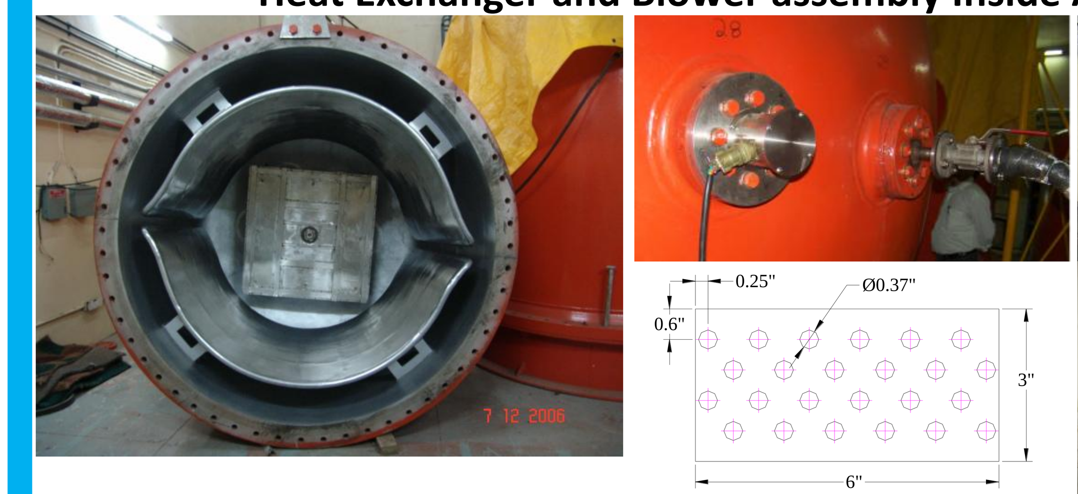
Nu_D = 0.023 ReD4/5 Prn   Where n = 0.4 for heating and 0.3 for cooling

These equations are valid for the range of conditions-

$0.7 \leq Pr \leq 160$ $Re_D \geq 10{,}000$ $L/D \geq 10$ where Re_D is Reynolds number, Pr is prantle numbe and Nu_D is Nusset Number.



Heat Exchanger and Blower assembly Inside Accelerator Tank



Rectangular Radiator type Heat Exchanger with Blower assembled

VFD, chiller, piping and connection with tank

Chiller plant along with heat exchanger and blower has been working with accelerator over more than 5 years. At low power level we do not run the blower, chilled water in finned tube is sufficient to cool the system. We run the blower for heat load more than 4 kW.Two number of electronic flow metering system with DP transmitter, orifice plate assembly and sensors are installed in both heat exchanger outlet pipeline for remote reading of flow.

Calculated heat transfer coefficient in SF_6 gas side is 400 W/m²K and on water side it is 8000 W/m²K. Over all heat transfer co-efficient is 200 W/m²K. Length of tube in tube bundle required is 76 meter.

FABRICATION AND TESTING

Fabrication & testing of SF_6 gas cooling system like piping, heat exchanger are carried out as per ASME B31.1 Code for pressure piping. Raw material identified in the form of pipe as per ASME SA 312 TP Gr-316L. Physical, chemical and IGC test carried out.

Welding Performance Specification was carried out as per ASME code SEC-IX. Gas tungsten Arc Welding is used for piping joining. Complete pipeline including all flexible hoses, valves, pressure gauges, flow transmitter, etc was pneumatically tested at a pressure of 11.0 kg/cm²(g) and found satisfactory. Tube bundles inside accelerator tank are pneumatically tested at 20 bar pressure.

We have carried out Mass spectrometer leak detector (MSLD) testing of pipe line after hydro test. We have found leak in flexible bellow. It was decided to use Copper pipe with enough flexibility to give proper connection inside accelerator tank and it should take vibration of blower which is running inside accelerator tank.

SPEED AND VIBRATION CONTROL WITH V. F. DRIVE

A variable-frequency drive (VFD) is installed with system for controlling the rotational speed of an alternating current electric motor by controlling the frequency of the electric power supplied to the motor. The operating speed of a motor connected to a VFD is varied by changing the frequency of the motor supply voltage.

We have made the check list to see the different conditions before starting the cooling system. Operating procedure gives guidelines to operate cooling system in different heat load conditions.

During initial testing motor insulation breaks due to over current drawn and over current protection failed. A variable frequency drive installed to control the RPM of motor. It controls current and power limit of motor by controlling the RPM.

We have measured the vibration level and natural frequency of accelerator column. Blower RPM are set such a way that its natural frequency should not match with motor frequency. Also two blowers of accelerator tank and transformer tank should not give beat vibration. It is set at 18.6 Hz and 16.66 Hz in accelerator tank and transformer tank respectively.

TEST REPORT

i) Test Report of RF Tank Blower:

3HP/2.25kW, 4.5A, 1440RPM, 4 pole Motor Operating window: 360 - 720 RPM (12-24 Hz) At 33.8⁰C and 3.0 bar (g) SF_6 gas				
Motor speed RPM	Current, A	Power, kW	Voltage, V	Motor Active Current, A
360	2.49	0.25	103	1.06
400	2.64	0.32	115	1.3
500	3.08	0.55	145	1.93
600	3.71	0.90	176	2.74
720	4.6	1.48	215	3.8

ii) Test Report of Accelerator Tank Blower:

Acc. tank 2HP/1.5kW, 3.2A, 1440RPM, 4 pole Motor Operating window: 360 - 720RPM (12-24 Hz) At 33.8⁰C and 3.0 bar (g) SF_6 gas				
Motor speed RPM	Current, A	Power, kW	Voltage	Motor Active Current, A
360	1.66	0.14	102	0.53
400	1.70	0.17	113	0.62
500	1.86	0.28	142	0.94
600	2.11	0.44	173	1.31
720	2.54	0.72	210	1.84

CONCLUSIONS

The SF_6 gas cooling system is running at desired capacity. Blower was running through VFD at set frequency of 18.6 Hz (558 rpm) and 16.66 Hz (498 rpm). Differential pressure flow transmitter, control of chiller unit and VFD control are remotely operated from control room. At 1 MeV beam power only chilled water circulation is sufficient after that blower is also required for heat removal. Accelerator has been operational at 10 kW power level.