HIGH POWER RF FOR TRIUMF INJECTOR CRYOMODULE AND ELINAC

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Abstract

A 500 kW electron linear accelerator is being proposed at TRIUMF for radioactive ion beam production to support the existing rare isotope facility. Present design consists of a 300 keV thermionic gun, a normal conducting buncher, an injector module and two main linac modules. The design energy is 50 MeV with 10 mA beam current. The linac will operate in cw mode using 1.3 GHz superconducting technology. The injector cryomodule (ICM), uses a nine-cell TESLA type cavity operating at 2 degrees Kelvin with a design energy of 10 MeV. The front end of the ICM has a room temperature buncher which will be fed by a solid state amplifier. A 30 kW 1.3 GHz IOT, operating at cw mode will be used to drive the nine-cell cavity of the ICM. The rf power will be divided into two equal parts and fed to two TTF III type couplers. The same couplers are intended to be used for the remaining accelerator cavities of the e-linac. The e-linac is being proposed to be built in stages. High power Klystrons will be used to provide rf power to the accelerating cavities.

INTRODUCTION

The cw electron linac which has been approved for construction, has a final energy of 50 MeV with rated beam current up to 10 mA. The radio frequency systems of the e-linac injector consist of a 300 kV grid modulated electron gun, a room temperature buncher, an injector cryomodule (ICM) consisting of a single 9-cell TESLA type cavity operating at 2 degrees K. The accelerating structure of the e-linac is comprised of two cryomodules, each cryomodule consisting of two 9-cell cavities. The beam energy at the exit of the ICM is designed to be 10 MeV and the final energy at the end of the linac is 50 MeV. The injector and the ICM 30 kW beam test is scheduled to be completed by March 31, 2012 and electron beams at 25 MeV, 100 kW will be delivered by March 31, 2015. In this paper radio frequency systems pertaining to the buncher, the ICM and the main acceleration cavities will be discussed. The rf modulation of the e-gun will not be discussed here. The high power rf for the ICM employs a 30 kW cw IOT and for the accelerator downstream of ICM, high power cw klystrons are proposed. The buncher is fed by a solid state rf amplifier. All the rf systems described here operate at 1.3 GHz in cw mode.

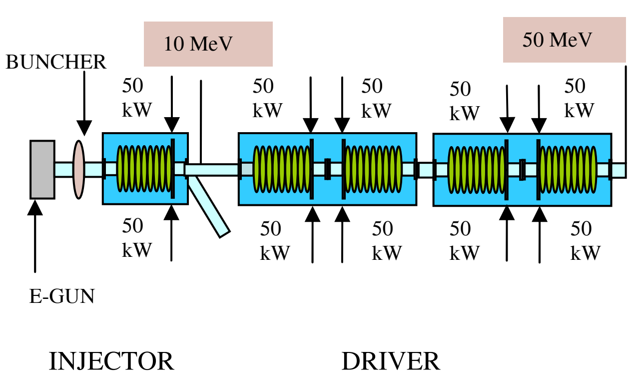

Figure 1: Basic layout of the E- linac.

E-LINAC Basic Concept

The base line design of the linac uses a 300 keV electron gun with grid modulation at 650 MHz. This is followed by a normal conducting buncher, an injector linac (ICM) operating at 1.3 GHz. This is followed by two cryomodules which have two 9 cell cavities per cryomodule. The cavities for ICM and accelerating sections are made of bulk Niobium and operate at 2 degrees Kelvin. Figure 1 shows the schematic of the linac with two 50 kW couplers per 9-cell cavity. It should be noted that the previous base line concept of the e-linac had 100 keV electron gun and two capture sections in the injector cryomodule (1).

INJECTOR RF SYSTEM

The Buncher

The normal conducting buncher has been designed and manufactured by NIOWAVE, Inc., USA. The quality factor and the shunt impedance of the buncher are 20,000 and 4 MΩ respectively. Figure 2 shows the photograph of the buncher. The buncher will be powered by a solid state rf amplifier operating at 1.3 GHz in cw mode. For a low brightness beam, with a peak buncher field of 0.5 MV/m, the voltage required for the buncher is 29 kV and the phase angle is -90 degree (2). Table 1 gives the basic parameters of the buncher and the rf amplifier. The generator power required to produce the bunching voltage is 420 watts. With insertion loss of connecting cables, connectors and directional couplers, total rf power demand is 640 watts. Hence a 640 watts solid state amplifier operating in class B has been specified for procurement. The buncher is equipped with a frequency tuner and a pick up probe. The power coupler for the buncher will be procured soon.

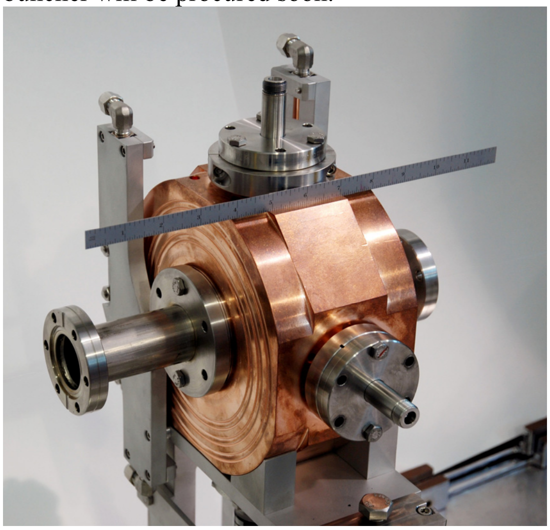

Figure 2: Photograph of a normal conducting 1.3 GHz buncher cavity.

Table 1: Basic Rf and Beam Parameters of the Buncher

Buncher cavity parameters	
Buncher shunt impedance	4 MΩ
Buncher Unloaded Q	20,000
R/Q	200
For given parameters	
Buncher conduction angle	-90 degree
Buncher voltage	29 kV
Conduction angle	-90 degree
Average beam current	10 mA
Computed parameters	
Generator current	14.5 mA
Frequency shift	70.4 kHz
Power dissipated in the buncher	105 watts
Generator power at the cavity	420 watts
Detuning angle	47.3 degree
Maximum induced cavity voltage	60.4 kV
Amplifier Output power	640 watts

The 30 kW IOT

The injector cryomodule will be powered by a 30 kW IOT (Inductive Output Tube) operating in cw mode at 1.3 GHz. The IOT model number VKL 9130A has been purchased from CPI, USA and has been tested at the factory both for cw and pulse operations. Figure 3 shows the photograph of the IOT and figure 4 shows output power, gain and efficiency as a function of rf drive during the factory acceptance test of the IOT.

The IOT Transmitter

A transmitter for the IOT consists of a dc beam power supply, a heater power supply, a focusing magnet power

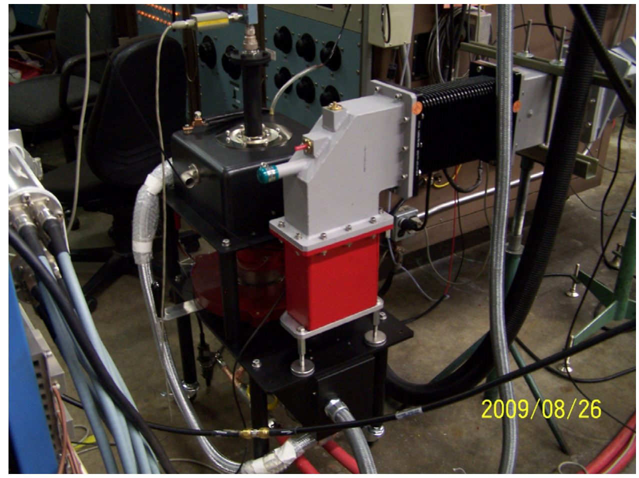

Figure 3: Photo of the 30 kW IOT in a test set up at the factory.

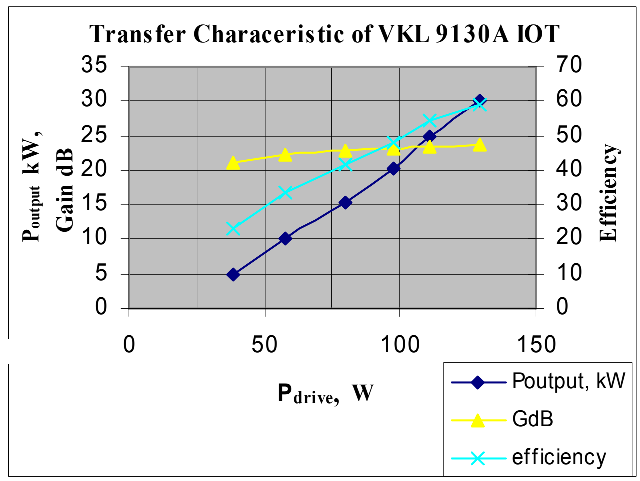

Figure 4: RF measurement of the IOT up to 30 kW output power.

supply and an ion pump power supply and interlock , monitor and control functions. It has been bought from Bruker BioSpin, France and has been tested at the factory prior to delivery to TRIUMF. The transmitter also includes a circulator at the output of the IOT and a dummy load for the circulator and a class B linear driver amplifier. The measured characteristic of the amplifier is shown in table 2. Figure 5 shows the gain and the phase measurements of the amplifier from 10 watts to 360 watts output power. The dc supply for the IOT beam employs a switching mode power supply which does not require any crowbar circuit to protect the IOT in case of arc in the output wave guide window. This is demonstrated by a short circuit test using AWG32 15 cm long wire at the output at 35 kVDC. The measured time delay is less than 6 µsec and the stored energy is computed to be less than 6 joules. The stored energy of the IOT is specified to be less than 10 joules for protection of the device should an arc occur internally or externally to the tube.

Table 2: RF Parameters of the Bruker Solid State Driver Amplifier

Frequency Range	1295-1305 MHz
Output Power at 0dBm Input	370W
Linear Output Power at 1dB compression	385W
Max. Output Power	400W
Average Small Signal Gain	57.3dB
Gain Flatness	0.86dBpp max.
Gain Linearity	±0.5dB
Overall Phase Shift (O/P Pwr. = 10-385W)	±4.6°
-3dB Gain Bandwidth	1261-1340MHz
Harmonics, 2nd and 3rd	-39.7dBc, -46.2dBc
Input Noise Figure at 1300 MHz	8.4dB
RF Pulsing, 1 KHz rep. rate	200W Peak
5% to 15% duty cycle	10 W to 30 W average
Efficiency	31%
AC Power for RF output power of 385 W	1.23 kW

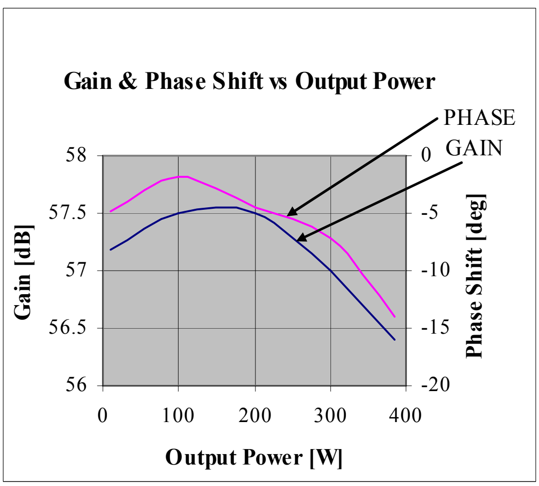

Figure 5: Gain and phase measurement of the solid state driver amplifier.

ACCELERAOR RF SYSTEM

High Power Klystron

The main accelerator (Driver) followed by the injector consists of two cryomodules, each module has two 9-cell TESLA type cavity operating at 2 degree Kelvin, producing 20 MeV energy gain per cryomodule. With beam current of 10 mA, the total rf power required for the main accelerator is 400 kW. Thus each 9-cell cavity will require 100 kW of rf power at 1.3 GHz which will be provided by klystrons. Either four 150 kW klystron or two 300 kW klystron will be used to meet the above demand of rf power. A basic schematic is shown in Figure 6 using one 150 kW klystron. Table 3 shows the estimated rf losses in the system.

High Power Coupler

Each 9-cell cavity is equipped with two power couplers mounted on the beam pipe perpendicular to the beam axis but at 180 degree apart. Since commercially available power couplers are not available for a 100 kW cw rating, two power couplers rated for 65 kW each will be used to feed one 9-cell cavity. Two such high power couplers CPI model VWP3032 have been procured. The same couplers are also used to power the ICM 9-cell cavity.

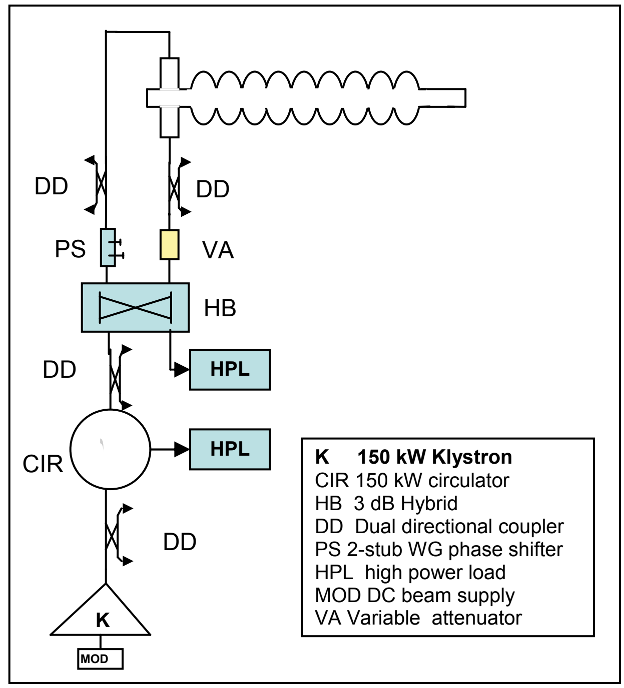

Figure 6: Basic scheme of 150 kW klystron rf system.

Table 3: Losses in Waveguide Components for High Power Klystron System

Waveguide, Aluminum: loss 0.21 %/m	
For 12.0 m, 100 kW, loss	2.52 kW
Sum of losses due to Circulator (100 kW) 0.15 dB , 3dB Hybrid 0.1 dB , Directional coupler 0.04 dB X 4, 2 stub phase shifter 0.04 dB, E and H bends 0.01 dB X 8 = 0.53 dB which is equivalent to loss factor of 0.11	11.0 kW
Hence, total loss including waveguides	13.5 kW
Klystron Output (linear range) required	114 kW
Klystron saturated output power	150 kW

REFERENCES

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[2] Y.C. Chao *et al.*, TRIUMF Design Note TRI-DN-10-08, "VECC Injector Baseline Component and Layout".