HIGH POWER RF SYSTEM FOR TRIUMF E-LINAC INJECTOR

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Abstract

TRIUMF and the University of Victoria is *funded to build the first stage of an electron linac with a final energy of 50 MeV and 500 kW beam power. The linac consists of an injector and two accelerator cryomodules to be installed sequentially. The injector is preceded by a thermionic gun and buncher cavity; the latter is driven from a Bruker 500W amplifier.

The injector cryomodule will be fed by up to two 30 kW cw Inductive Output Tube (IOT), while the accelerator will be powered by two cw klystrons. A first goal is a beam test of the injector to 10MeV in 2012. Installation and full rated output power tests of the IOT on a 50 ohms load have been carried out. The IOT is purchased from CPI, USA while the transmitter is sourced from Bruker BioSpin, France. A power coupler conditioning station utilizes the same IOT. This paper summarizes the conceptual design of the linac high power rf system and presents measurement results from the injector IOT system.

INTRODUCTION

The TRIUMF e-linac consists of an electron gun, buncher cavity, injector cryomodule (ICM), and two accelerator cryomodules (ACM) [1]. The injector has one 9 cell cavity whereas each of the accelerator modules contains two 9-cell cavities. The cavities operate at 1.3 GHz at 2 Kelvin. The final energy of the e-linac is 50 MeV with an average current of 10 mA. Each 9 cell cavity has two Cornell/CPI power couplers rated up to 65 kW. The injector module will be fed by 30 kW cw inductive output tubes (IOT); and accelerator cavity pairs will be powered by a 300 kW cw klystron. The linac will be built in stages. In the first stage, to be completed by mid-2014, a single IOT for the ICM and a 300 kW klystron for the first ACM will be installed providing a minimum beam energy of 25 MeV, 4 mA. In the second stage, to be implemented in 2017, the second ACM is added along with a second 300 kW klystron, and second IOT for the ICM, to achieve the final beam power of 500 kW goal [2]. The basic layout of the e-linac is shown in figure 1.

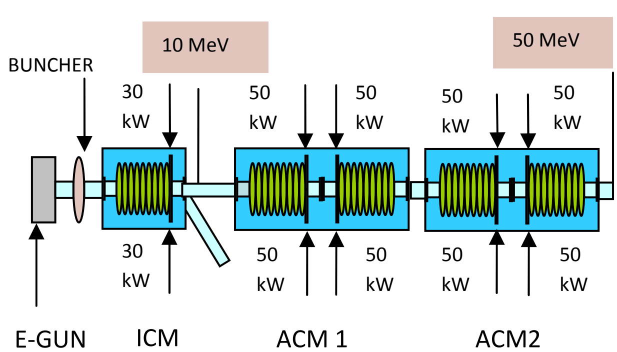

Figure 1: Basic layout of the E-linac

CONCEPTUAL DESIGN OF THE E-LINAC RF SYSTEM

The high power rf conceptual design outlines the rf power distribution scheme with 30 kW IOT and a 300 kW klystron. [3]. Power couplers that will be used in all these cavities are obtained from CPI, model VWP3032. For the first stage of installation, the 30 kW output power of the IOT will be split into two to provide rf power for 2 couplers in the ICM. A second 30 kW IOT will be added in the second phase of installation, thus bringing the total rf power installed in ICM to be 60 kW. The first cryomodule, ACM, consisting of two 9-cell multi-cell cavities will require four power couplers operating at 50 kW cw. A 300 kW klystron will be adequate to provide this power. 3 dB hybrids and phase shifters will be used to divide power equally and maintain required phase of the rf voltage in the accelerating cavities with respect to the beam. Two 30 dB variable attenuators are employed for rf conditioning the cavities, one cavity at a time. The variable attenuator will be kept at minimum attenuation for the cavity to be conditioned and the other attenuator will be kept at maximum attenuation for the cavity that is not being rf conditioned. Another solution is being pursued in which a variable power divider with constant phase would replace the variable attenuators.

BUNCHER CAVITY AND RF AMPLIFIER

The buncher will be installed between the gun and ICM. The 1.3 GHz buncher cavity is of the Daresbsury-EMMA design, and has been procured from Niowave, USA.

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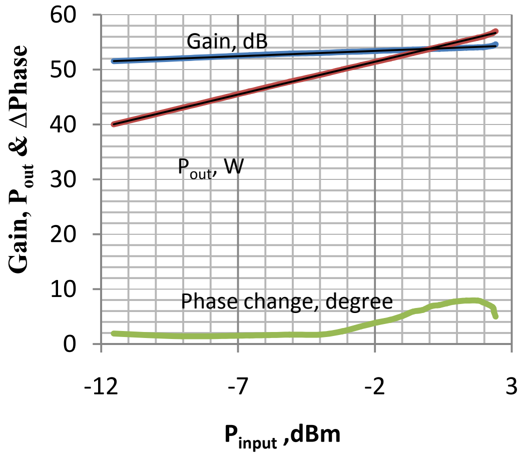

Figure 2: Measured rf characteristic of the solid state buncher amplifier

The measured Q and shunt resistance of the buncher are 20,000 and 3.3 MΩ [$V^2/(2P)$ definition, transit time factor 0.78] respectively and R/Q is 200. With these cavity parameters, gap voltage of 30 kV and beam current of 10 mA [4], the minimum and maximum generator power required for phase angle of -90 to -90±15 degree are 160 watts and 290 watts respectively. A solid state amplifier, model BLA500CW, Bruker BioSpin, France, operating in class AB and providing 400 watts (maximum available power is 500 watts) of rf power, has been procured. Measured gain, phase variation and power output versus input drive power are shown in figure 2. The buncher is ready for installation in the beam line for the ICM test which is scheduled for 2012.

30 kW IOT AND THE TRANSMITTER

The 30 kW cw RF transmitter at 1.3 GHz consists of a 30 kW IOT, CPI model VKL9130 and a transmitter from Bruker BioSpin. The transmitter consists of a switch-mode power supply for the IOT beam voltage, filament

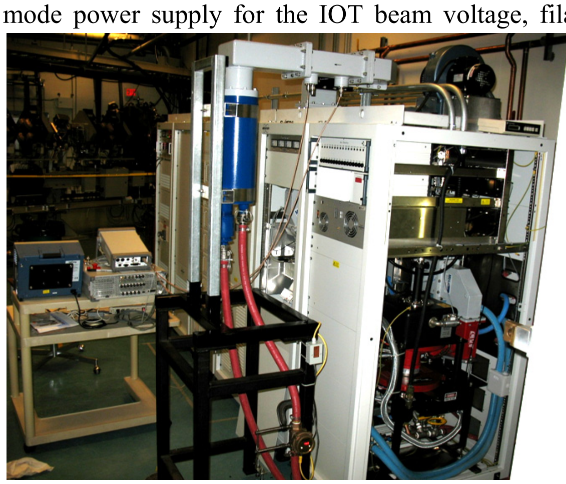

Figure 3: Photograph of the IOT Transmitter

power supply, focus power supply, grid bias power supply and power supply for ion pump. The unit also contain rf driver amplifier, an AFT circulator and WR650 waveguide directional couplers. Figure 3 shows the transmitter and the IOT and the output waveguide at the top of the cabinet connected to a water cooled dummy load. The solid state driver for the IOT is also installed in the transmitter, and operates in class AB and provides 400 Watts RF power. The transmitter is also equipped with interlock and interface electronics and provisions for local and remote operation via Ethernet/RS232.

The CPI IOT was fully tested at the factory to 30 kW cw RF output prior to shipping to TRIUMF. The IOT transmitter power supply and the driver were tested in the factory and was installed at TRIUMF and rf output of 25 kW cw was obtained in December 2010. The operating goal of 30 kW could not be attained due to arc pulse fault and rf interference with the power supply ground. The problem was resolved by re-routing the grounding and establishing a single point ground. Since then, the IOT

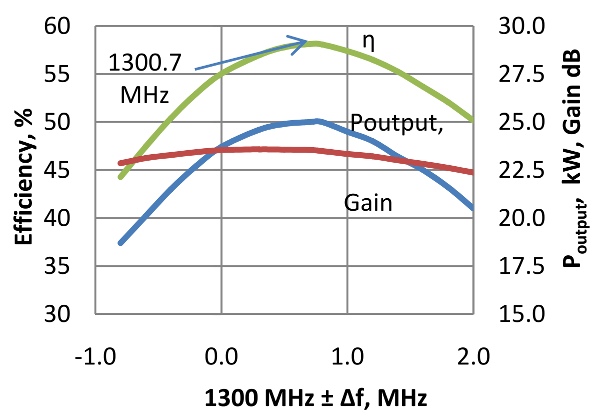

Figure 4: RF measurements of 30 kW IOT s/n 001

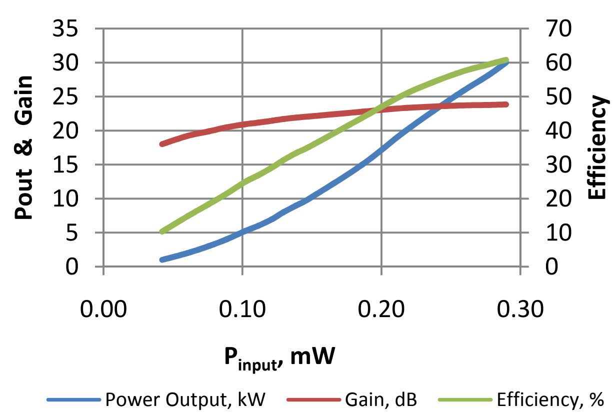

Figure 5: Variation of gain, output power and efficiency of the IOT with frequency at 25 kW nominal power

transmitter has been able to produce 30 kW output power on a regular basis. It has been kept running cw at 30 kW for 24 hours, at 25kW for 40 hours and at 20 kW for 7 days without a single trip. IOT RF measurements are shown in figure 4 and 5. Measurements done independently at CPI and TRIUMF agree very closely as shown in Table 1.

The control interface via EPICS/RS232 and interlocks are not fully operational due to malfunctioning of the control unit of the transmitter which has been sent to the factory for repair.

Table 1: Summary of Measured Parameters of the IOT

Measurements at			CPI	TRIUMF
Beam Voltage	Eb	kV	35.1	35.0
Beam Current	Ib	A	1.38	1.41
Quiescent Current	Iq	mA	6.0	1.0
Vac ion Current	Iip	μA	0.60	0.57
Grid Voltage	Eg	V	-80.2	-80.0
Grid Current	Ig	mA	-3.1	0.8
Focus Current	Isol	A	21	21
Focus Voltage	Vsol	V	7	6.65
Heater Voltage	Ef	V	9.5	9.0
Heater Current	If	A	8.1	8.1
Output Power	Po	kW	30.5	30.0
Drive Power	Pd	W	190	124
Efficiency	Eff	%	63.0	60.8
Gain	Gain	dB	22.0	23.8
Bandwidth (-1 dB)	BW	MHz	2.5	2.7

300 kW KLYSTRON FOR ACM

In a joint venture with Hertzberg Zentrum Berlin, an order has been placed with CPI, USA, for the 300 kW cw klystron, which will be required for the accelerator cryomodule. This klystron is designed to deliver RF output power to at least 270 kW (rated for 290 kW) with the incremental gain to be equal or larger than 0.5 dB/dB. This klystron has a specified perveance of 0.55 $\mu A/V^{1.5}$ and beam voltage of 65 kV; and efficiency is expected to be minimum 52%. The original specification of the klystron [5] was 300 kW saturated power with 1 dB compression point at 250 kW. With estimated power loss of 21% in the waveguides and waveguide components, estimated available rf power at the cryomodule is 210 kW cw. This power will be divided and fed to four power couplers (there are 2 power coupler per 9-cell cavity, and 2 cavities per accelerator cryomodule). Thus 52.5 kW rf power will be available at each power coupler. Two power couplers, CPI model VWP3032, rated at 65 kW cw at 1.3 GHz have been purchased and are being prepared for tests on a coupler test stand. A crowbar less switching mode power supply for the klystron beam will be located about 40 meters away from the klystron. To limit the stored energy <15 joules in the klystron in case of a internal tube arc, a suitable snubber circuit at the cathode of the klystron will be designed and implemented.

COUPLER TEST STAND

The power couplers intended to be used for the ICM and ACM cavities, are being prepared to be tested in a coupler test stand. Figure 6 shows two couplers cold windows mounted on a waveguide box. The 30 kW IOT transmitter will be used for the coupler test. Initially rf power will be limited to 10 kW cw for rf conditioning and thermal test of the couplers.

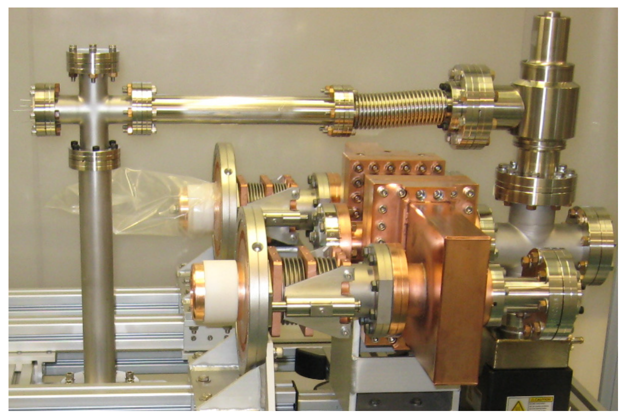

Figure 6: Coupler test stand - two CPI 65 kW coupler cold windows are mounted on a waveguide box

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