HIGH POWER RF SYSTEM FOR e-linac FOR TRIUMF

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Abstract

The TRIUMF e-linac high power system will be built in stages. For the first phase of installation to be completed by September 2014, the injector cryomodule (EINJ) will be fed by a 290 kW cw klystron at a reduced power level and the accelerating cryomodule (EACA) will be powered by an identical klystron. The first 290 kW 1.3 GHz klystron has been purchased from CPI, USA and the high power supply system has been bought from AMPEGON, Switzerland. The second klystron and second high voltage power supply are being procured from the same manufacturers. The 290 kW cw 1.3 GHz klystron is a factory tuned multi-cavity, high efficiency, high gain, broadband, water cooled tube. The klystron has been tested at the factory. The maximum usable linear range of the rf output power of the klystron is 270 kW and is governed by the incremental gain of 0.5 dB/dB. Thus, rf power required for EACA of 200 kW cw is adequately met by the klystron after taking into account the loss in the waveguide components. and waveguides. The high voltage power supply system (KPS) for the klystron, based on a voltage controlled power module technology, consists of 65 kV beam power supply, focus supply, filament power supply and vacuum ion pump power supply. The klystron will be tested to full power on a dummy load by October 2013. At the same time, the KPS will be tested fully with all controls, interlocks, protections and integration of the klystron and a 300 kW high power circulator.

INTRODUCTION

The TRIUMF e-linac consists of an electron gun, buncher cavity, injector cryomodule, and two main-linac cryomodules [1]. The injector module has one 9 cell cavity whereas each of the accelerating (main-linac) cryomodules contains two 9-cell cavities. The cavities operate at 1.3 GHz at 2 Kelvin. The nominal energy of the e-linac is 50 MeV kinetic with an average current of 10 mA. Each 9 cell cavity has two 60 kW high power couplers. Two 290 kW CW klystrons will be employed to feed injector cryomodule (EINJ) and the accelerating cryomodule (EACA). However, the klystron for the injector will be operated at reduced output power. The linac will be built in stages. In the first stage, to be completed by September 2014, a minimum beam energy of 25 MeV, 4 mA will be obtained using the 290 kW klystrons. In the second stage, to be implemented in 2017, a second accelerating cryomodule (EACB) will be added and a 120 kW rf generator will be procured which will feed the injector. The two 290 kW Klystrons will be restored to full power operation to feed the first and the second accelerator cryomodules, to achieve the final beam power goal of 500 kW.

BASIC SCHEME OF THE HPRF SYSTEM

The basic scheme of the high power rf system for the first accelerating cryomodules is shown in Figure 1. The injector has 1 9-cell cavity and will be powered by one 290 kW klystron at a reduced power level whereas the accelerating cryomodule EACA will be run by the second klystron operating at full power. A variable power divider has been employed to facilitate rf conditioning of the two 9-cell cavities in EACA cryomodule. Also, variable phase shifters are employed to achieve phase balance between two couplers in the same cavity and for phase balance between adjacent cryomodules. The major components of the high power rf system is outlined in the following sections.

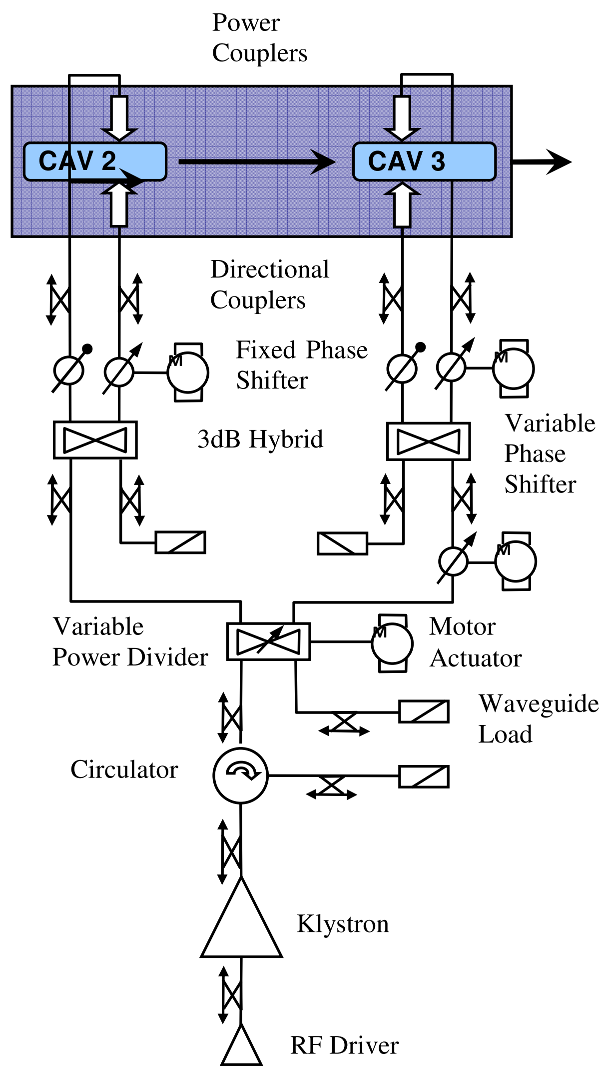

Figure 1: Basic schematic of HPRF system for the first accelerating cryomodule for e-linac

CHOICE OF KLYSTRON

The choice of commercially available high power cw rf sources operating at 1.3 GHz is very limited. Using a 150 kW klystron (available power at the cavity is about 120 kW) for each cavity would have been the ideal choice for e-linac since it would have utilized fully the rf coupler power handling capacity (60 kW operational rating, 75 kW maximum) and provide simple and straight forward low level rf control. Such a system would be very expensive and also a 150 kW klystron is not commercially available. A 290 kW cw klystron, CPI type VKL7967A, shown in Figure 2, has been recently developed jointly with HZB, Berlin and TRIUMF and has been tested at the factory. This solution has been found to be suitable for the e-linac high power rf system and fits to the tight time schedule and available funding of the project. Figure 3 show the measured output power vs drive power for two different operating conditions. The basic parameters of the klystron are listed in Table 1. An oil tank houses the filament and the cathode of the klystron and a snubber is attached to the cathode circuit to limit the stored energy less than 15 joules. Some of the basic parameters for 290 kW and 150 kW operation are, beam voltage 60.5 kV/48.5 kV, beam current 8.1 A/6.8 A, rf drive power 8.0 w/11.0 w, rf efficiency 53%/48% respectively.

Figure 2: CPI type VKL7967A 1.3 GHz cw klystron

HIGH VOLTAGE POWER SUPPLY FOR THE KLYSTRON

A 65 kV, 10 A dc power supply (referred as KPS) has been developed by AMPEGON, Turgi, Switzerland for the CPI klystron. The power supply utilizes 12.5 kV AC 3 phase input and has a transformer with 48 secondary outputs. Each output is connected to a dc switching mode.

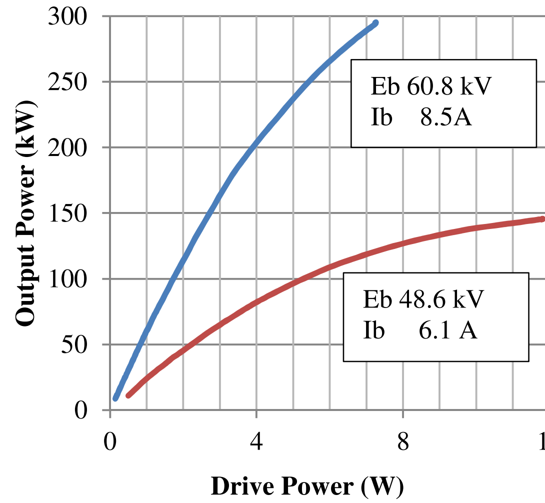

Figure 3: Output power vs drive power of the klystron module.

A novel low ripple enhanced PSM (power switching module) technology has been employed for the cathode power supply [2]. The dc voltage can be varied from 0 to 65 kV with a ripple <0.1% and a efficiency >96%. The KPS contains all required auxiliary power supplies to operate the klystron, rf driver amplifier, amplifier control and fast interlock system. For safety and maintenance of the KPS, a manual disconnect is interposed between the power supply and the Siemens switchgear which supplies all AC power requirement for e-linac. TRIUMF safety system will provide a +24 volt ENABLE control signal for the KPS and will initiate a trip by withdrawing this ENABLE control signal. The power supply has been tested at the factory for all functions, interlocks and local control. Short circuit was applied to a dc cable connected to the dc output of the KPS and the test showed that the output current increases from 0 to 40 amps in 10 µs while output voltage goes from 65 kV to 0 volts. The KPS is now installed at TRIUMF in its final location and is undergoing commissioning Figure 4 shows the photo of KPS being installed at TRIUMF.

Figure 4: AMPEGON KPS at final location at TRIUMF

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300 KW CW CIRCULATOR

A high power circulator is connected at the output of the klystron in order to protect it from high reflected power arriving at the klystron output window due to mismatch of the coupler-cavity impedance or arc in the waveguide components. The circulator, rated for 300 kW cw, is water cooled and has an arc protection system. A low-loss glass fiber cable transfers the light of an arc detected with a high sensitive photodiode to the optical input of the arc detector module. The circulator and two 300 kW dummy waveguide loads and system integration is provided by COMARK, USA.

VARIABLE POWER DIVIDER

A variable power divider was chosen to divide power for the two cavities of EACA and was procured from MEGA Industries. During normal operation of the accelerator, the power divider will be set to mid-value so that power from klystron is equally divided and is fed to the two EACA cavities. Since, the cavities are rf conditioned via a self excited mode dictated by low level rf system, the variable power divider will be set for maximum power transfer to the cavity to be conditioned. For rf conditioning the cavities, 2 to 4 kW cw and 5 to 15 kW pulse power may be required depending on the coupling of the power couplers to the cavity. Maximum attenuation of 37 dB of incident power can be achieved with a maximum insertion loss of 0.17 dB.

VARIABLE PHASE SHIFTER

Variable phase shifters are required to balance the phase of the RF input couplers on the same cavity. These variable phase shifters should have more than 120 degrees of phase shift to compensate for tolerances in the waveguide assembly. Also, phase shifter is required to compensate for phase shift between two adjacent 9-cell cavities in the same cryomodule. Multiple solutions were investigated using two stub phase shifter, three stub phase shifter and a hybrid based phase shifter. Simulations were conducted for each case. The two stub phase shifter is not capable of providing the required phase shift; however, the three stub phase shifter can provide the phase adjustment required but requires at least two motors (or three, if two are not ganged together) with independent controllers. The relationship between phase and position of the stubs is not straightforward, so calibration and intelligent control is needed. The hybrid coupler based phase shifter requires significantly more room but has an excellent phase shift characteristic with the movement of the short circuit. The simulation of such a phase shifter shows a phase change of 22.5 degrees occurs for 1 cm change in stub position The simulated insertion less and return loss are <0.1 dB and <-23 dB respectively for the complete range of phase shift.

Table 1: Parameters of CPI Klystron Type VKL 7967A

Operating Frequency Mid-band	1300 MHz
CW Output Power	290 kW
RF Power Gain at nominal beam voltage	42 dB
Usable CW Output Power[1]	270 kW
Usable DC to RF Efficiency[1]	52 %
VSWR Tolerance, maximum	1.2:1
-1 dB Bandwidth	2.0 MHz
-3 dB Bandwidth	6.0 MHz
Klystron Beam Voltage	62.5 to 65 kV
Klystron Beam Current, maximum	9.1A
Beam Perveance, minimum	0.55 $\mu A/V^{1.5}$
Collector Dissipation, maximum	600 kW
Body Dissipation (without Output)	1% P_{beam}
Tuning	Fixed tune
Beam Focusing	Electromagnet
Phase shift of Output Power to Beam Voltage shift at operating beam voltage	<0.05 degree/volt
Output Wave Guide	WR-650
Cooling	de-ionized water
RF Input, coaxial	Type"N"
Note 1: for incremental gain, IG >0.5dB/dB	

INSTALLATION AND TEST OF THE KLYSTRON

It is proposed to commission the KPS and test the klystron by October 2013. At first, the KPS will be tested for all interlock functions, safety switching on/off procedure with Siemens switch gear and manual disconnect and key sequence for lock out procedure. The front touch panel will be also tested to bring up the KPS in a controlled mode. After short circuit test of the dc output is done, the dc high voltage cables will be connected to the klystron. In the mean time, the klystron will have a snubber installed in the oil tank the focus, filament and vacuum ion power supplies connected and water cooling will installed. The circulator and the two dummy loads will be connected to begin the high power test of the system. EPICS control system interface will be commissioned. This will allow control of the KPS system as well as monitoring the temperature and flow of the water cooling system of the klystron, the circulator and the two loads and the dc parameters of the KPS-klystron system.

REFERENCES

[1] S. Koscielniak et al, "The ARIEL Superconducting Electron Linac", LINAC12, Tel Aviv, Israel, Sept 9-14, 2012.

[2] M. Frei, M. Bader, et al, "Ampegon's New Klystron Power Supply System for the Triumf E-Linac 1.3 GHz/270kW cw RF System", IPAC13, Shanghai, China, 12-17 May 2013.