Power Supply System for 324 MHz Klystron of the JHF Proton Linear Accelerator

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Abstract

A proton linac of the JHF will consist of several frequency rf-sources depending on the accelerating structures. The low energy part of the linac (RFQ, DTL, and SDTL) are now planned to be driven by 324 MHz Klystrons. High power and high duty power supply systems for these 324 MHz klystrons will be reported. The beam power of the klystron is supplied from a cathode high voltage capacitor bank with modulating the beam current by a modulation anode. The basic scheme of the power supply system is as follows. Four klystrons are connected to the common cathode voltage but the beam current of each klystrons are modulated independently. A crowbar circuit is equipped to bypass the huge energy stored at the capacitor if the shortening is happened at the klystron. Four klystrons in one system will be operated through two level control sequences of PLCs. The power supply system stated above is now starting to construct. Preceding to other components, one anode modulator has been already constructed. The present status of a design work and the test result of the modulator will be described.

1 Introduction

In the present scheme of the JHF proton linac, the low energy part of it (up to 200 MeV) will consist of RFQ, DTL and SDTL[1] accelerating structures and these will be driven by 324 MHz rf-power. Before starting a construction of the 200 MeV linac at the JHF site, a 60 MeV prototype linac is scheduled to be constructed at KEK site to clear the difficulties that will be encountered at the actual linac construction, and to show that the designed linac is feasible. High power and high duty rf-sources are required for these structures, so the klystron is adopted as the rf-power generator. The maximum operating-rate of the klystron is 2 MW power for 650 μs pulse-duration with 50 pps repetition rate. The rf-power stated above must be well controlled both in the amplitude and in the phase, therefor the klystron that can generate 3 MW at the same duty is required and will be operating at a condition for 2.5 MW saturated output. In this condition, the amplitude and the phase can be controlled by the drive power of the klystron (low level control) up to 2MW output with reasonable wide margin for stable klystron operation. The klystron equipped with the modulation-anode is adopted, so the adopted scheme of the high voltage power supply system is consisted with the dc-cathode voltage and the pulsed-modulating anode voltage. The later anode voltage is generated by dividing the cathode voltage with prefixed ratio. This configuration is almost the same as the JHP klystron power supply system[2] that was constructed at KEK for UHF(432 MHz) pulsed klystron. The basic configuration of new system is consisted with 4 klystrons connected to the common cathode voltage with independent anode modulation for each klystron. In order to suppress the cathode voltage sag within the reasonable range (<5%), large capacitor bank is adopted. The crowbar circuit is equipped to the system to protect the klystron from the damage caused by the stored energy at the capacitor. A special modification is carried out only for one system. Because the power required for the first klystron (for RFQ) of the linac is not so high, one klystrron of this system is supplied the reduced cathode voltage even though 3 remain klystrons can be supplied the nominal cathode voltage. As a trade off of this option, the stabilization of the reduced cathode voltage is not carried out; the stabilization of the nominal cathode voltage for 3 klystrons is carried out. And also, the crowbar circuit for reduced voltage is not installed. However, one merit of this option is that a degraded performance klystron can be used at this station if these will be exist. As stated, one power supply system contains many components to be operated or controlled such as 4 klystrons, the high voltage part of the power supply

Klystron	Max. Rating	comment
Frequency	324 MHz	
RF pulse width	620 μs	
Repetition Rate	50 pps	
max. Output power	3 MW	Vk>110kV for max. power
Saturation power	2.5 MW	at operation Vk
max. Operation power	2 MW	linear region
Cathode Voltage	102 kV	operation Vk
Beam current	44 A	
Mod. Anode Voltage	86 kV	
DC power supply	**Max. Rating**	**comment**
No. of Klystrons	4	
Voltage	110* kV	cathode vtg.
Current	6.3 A	ave. of Pulse current
Power	693 kW	
Pulse current	180* A	beam+ M. pulse cur.
Pulse width	700 μs	FWHM
Repetition rate	50 pps	
Duty	3.5 %	
Voltage Sag	5 %	
Capacitor Bank	25.5 μF	*(19.2, 6.4 μF)
Strd Energy at C-Bank	154 kJ	
M-Anode Modulator	**Max. Rating**	**comment**
Pulse Voltage	93 kV	depend on Kly.
M. pulse current	1 A	cur. at vtg. divider
Pulse width	700 μs	FWHM
Pulse width	620 μs	Flat top
Capa. of Floating box	250 pF	**objective
Capa. of Load	300 pF	**cable+Kly.anode
Pulse rise time	40 μs	**; objective: 20 μs
Pulse fall time	130 μs	**

Table 1. Parameters of the klystron and the power supply system. * : For the reduced voltage klystron, 73kV and 30A be supplied at max. ** : Estimated values, so rise/fall time may be changed depend on the actual capacitance values.

and also low voltage power supplies; for focus coil, for filament, and for ion pumps. The components concerning to the high voltage generation are set at a high voltage yard placed at the outside a klystron gallery. On the other hand, the components concerning to the klystron are set at the klystron gallery near to each klystron. These components scattered in places are all monitored their performances, and are controlled following the operation procedures through the two levels control sequences by the PLCs.

2 DC High Voltage

The maximum rating for one system as well as the parameters of the klystron are summarized in Table-1. The one special system can generate nominal 110kV for 3 klystrons and 73kV for one klystron as shown in Fig.1; the 120kV, and 80kV shown in the figure are maximum voltages corresponding to no loading condition (no beam current). Neglecting this reduced voltage part, the rectifying method is almost the same as the JHP power supply system[2]; step down ac 6.6kV to ac 600V, controlled by thyristors to stabilize the voltage and step up to generate the nominal dc voltage. The reduced voltage is given as a fixed ratio (2/3) of the nominal dc voltage; no direct voltage stabilization is carried out for reduced voltage. The capacitor bank are chosen to satisfy the voltage

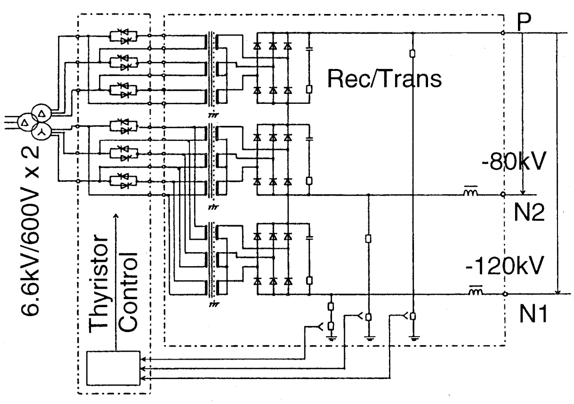

Fig.1 Schematic diagram of dc high voltage part.
The C-bank and the crowbar are also placed in this yard. The area size of these are, 2.3x 2.5 for rec/trans, 1.8 x 2.5 for C-bank, 1.2 x 3.5 for crowbar in the basic system. In the special system, more larger or extra parts are added.

sag below 5% at pulse duration; 25.5μF for 4 klystrons (for 3+1 reduced system, 19.2μF and 6.4μF are separately equipped). The maximum repetition rate is 50pps, so a resonant frequency of the rectifier is chosen as ~10Hz with ~10H choke coil. Some fear may rise if we try low repetition rate (1 ~ 10Hz) operations that will be reasonably expected at conditioning periods of the klystron or cavities. However, the experience at JHP power supply and the result of the numerical simulation indicate the stable operation at such low repetitions. So we adopt these parameters with the reasonable size of choke coil; the JHP system was designed as almost the same parameters except the number of klystron for one system. The generation of dc high voltage stated so far, is simple in principle and may be cheap for construction, but the relatively large sag is inevitable consequence unless a big capacitor bank is adopted. The sag of 5% may be practical choice from the several points of view; size, cost and the stored energy. The last point is important if the crowbar circuit is installed in the system with using ignitrons as switching device. The phase control of klystron output is another point to be discussed; more than 10° shift for 1% voltage sag, this correspond to >60° phase shift at pulse duration at most. The smaller phase shift (smaller sag) is preferable for precise phase control, if it is required. A bouncer circuit is one possibility for compensating the sag by generating anti-sag voltage and imposing it to the cathode voltage at the pulse duration. The rectifier/trans part is prepared to be isolated from the ground with 20kV withstanding voltage, even though no practical design of bouncer circuit is started yet. Four klystrons are connected to the one power supply system via 4 disconnection devices (DISCON) prepared for each klystron; for the basic 4 nominal voltage system, dividing into 4 branches after passing through the crowbar, and for 3 nominal+1 reduced voltage system, branching into 3 after the crowbar but not passing through the crowbar for 1 reduced line because the crowbar is omitted in this line. The DISCON is prepared to disconnect the klystron/socket easily and to insure the safety at the remaining klystrons are operated. The area of the high voltage yard for one system is ~100m^2. The rect/trans, the thyristor control unit, the capacitor-bank, the crowbar and a local control unit of these are placed there. The DISCON is placed in the klystron gallery just before the modulator.

3 Crowbar Circuit

The crowbar equipped with 6 series ingnitrons (NL-35391) is designed to install just after the C-bank in the high voltage yard. The long distance between the crowbar and the klystron is expected in the present layout of the linac; the high voltage yard is placed at outside the klystron gallery and the expected co-axial cable length connected between them may vary from a few 10m to 100m. Even though the energy stored at the co-axial cable is not so small compared to 20J (the maximum allowed dissipation energy at shortening), we adopt this configuration. The one reason is that a large portion of the stored energy at the cable is reflected back to the power supply side when the flash over happened at the klystron. The dissipation power is usually estimated as arcing voltage times current (60-100 V x I A), then the small dissipation energy is expected for first one pulse duration which is determined by cable length; 2 x τcable. The dissipation energy contributed from the following pulses is negligibly small because of approximate cancel out caused by an alternate polarity change, and because of the damping of the magnitude of pulses by a series resistance that is installed in the high voltage line at the klystron side after the long co-axial cable (actually installed in the anode modulator tank). These behavior were observed experimentally in the cu-wire shortening tests carried out at TRISTAN klystron power supply with using long cables (50, 100, 200m length), and discussed in ref.[1]. The energy flow from the primary line (ac 6.6kV) is also expected to be small, because of a quick shut off (~5ms) the primary power with reducing ac current by the thyristor control. Therefor the speed of crowbar work and the value of the series resistance are major parts to determine the actual dissipation energy for the given capacitance of C-bank and dc high voltage, irrelevantly to the crowbar position; whether it is before or after the long cable. In the JHP system, a relatively larger series resistance such as 27.5Ω is adopted with <6μs crowbar speed for intending <10J energy dissipation. Still rough but a little more precise estimation may indicate 10-20 resistance with the same crowbar speed for <10J dissipation even for larger C-bank capacitance. The larger the value of the resistance is preferable for decreasing the dissipation energy at the shortening, but the smaller the value of it is preferable for dissipation power at this resistance in the normal operation; ~20kW dissipation for 27.5Ω. The cu-wire shortening test at the actual system may decide final value of the resistance. Because the other important parameter Leff's (a inductance for the flash over current from C-bank) are depend on the actual layout and hard to estimate.

4 Anode Modulator

The high voltage for the modulation is generated by a resister-chain voltage-divider which is installed between the cathode voltage and ground level, and is pulsed by a hard tube switching device (TH-5188), as shown in Fig.2. A dc reverse bias voltage (-2 to -3kV) is imposed on anode voltage with followed by 10kΩ to insure a cut off state of klystron at inter-pulse period. An isolation transformer for klystron filament, and the series resister at cathode voltage are also installed. The pulse current stated in Table-1 (as 1A) is the current at the voltage-divider in the pulse duration, and this large value current insure the almost constant voltage dividing

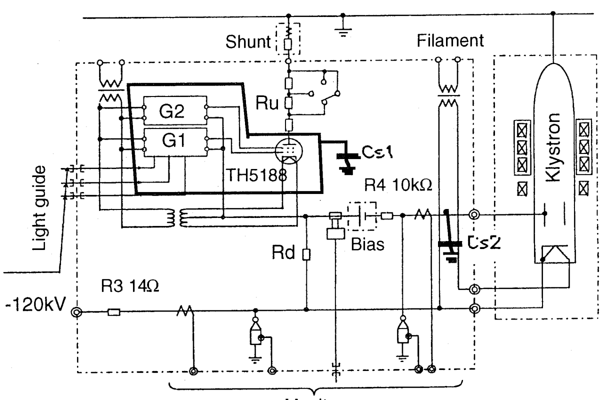

Fig. 2 Anode modulator tank. Stray capacitance are schematically showed; *Cs1 and Cs2*.

ratio even for ~100mA anode current. The actual dividing-ratio may depend on the required power and the klystron performance. The module of the resister-chain-set can be replaced easily. The Ru is selected from 3 taps of the module. The rise and fall times of the pulsed anode voltage are proportional to a sum of stray capacitance's formed by a floating box (Cs1) that contained the hard tube, and by the anode line load (Cs2); co-axial cable (~2m) and klystron anode with its socket. The modulator is set in the klystron gallery close to its klystron; just after the DISCON. An effort to reduce these capacitance's has been tried in the design work, and is almost realized in an actual modulator that is already constructed preceded to other components. It has been installed at JHP dc high voltage, and tested with a beam-test-tube for 324 MHz klystron[3]. The results are compared with a simulation and with old modulator as shown in Table 2. The simulation reproduces the data quite well, so this result indicate that the stray capacitance of the klystron-anode setting at the socket is ~260pF, if 200pF coming from 2m long cable is assumed; Cs2 - Ccable ≈ 260pF. In the design work, ~20μs and ~130μs are assumed as objective values for rise and fall time, respectively. Further efforts which may include a using of other type switching device, are required to attain (or to close to) these value under a limiting space condition. The size of the present tank is 1 (+.3) x 1.2 (+.32) x 1.5h (+.32) m^3 , where the value in the parenthesis indicate an amount of convex part. The components of the modulator displayed in the square box in figure 2, are all immersed in insulator oil.

	Attained	*Simulation	JHP:old
Rise time:10-90%	32 μs	31.3 μs	50 μs
Fall time :10-90%	183 μs	178 μs	390 μs

Table 2. Comparison of rise/fall time.
*Simulation condition; Ru=17kΩ, Rd=91kΩ, R4=10kΩ, Cs1=285pF, Cs2=463pF. Also capacitance of hard tube (plate-HV case) is included; 104pF. Cs1 is measured without hard tube and Cs2 is also measured value of ~5m cable. Objective(Table1): Cs1=250, Cs2=300pF.

5 System Layout and Control

The components of one power supply system are placed in two major separated areas such as the high voltage yard and the klystron gallery as stated before. In the klystron gallery, the components belonging to each klystron are grouped and set close to their klystron with other components such as the low level rf control modules. The gallery is placed just above the linac tunnel, and the klystrons are placed in 7m pitch in there, therefor the grouped components are also placed in the same interval. The places to be local control-station are scattered in wide area. From the point of view of the maintenance's of klystron and/or the power supply system, we must be able to operate the system in situ; at each klystron station and at the high voltage yard. Sequencer's (PLC) are adopted to control the system even in the most basic level controls; hard-wired relay sequence are almost all rejected, except at the safety control or at emergency controls. Two control levels (PLC1 and PLC2) are prepared. The level of PLC1 control the basic operations of the system, and this level alone can operate the system safely but in primitive ways. On the other hand, more sophisticated controls are carried out by PLC2 level with the safety of the system being relayed on the PLC1 and hard-wired relay sequences. Each control station in situ is selected exclusively as a master controller of the system, except for the operation of safety; high-voltage-off operation can be done at any station and at any time. The remote control of this system from the higher level network is obvious option.

References

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