

RF Power System for Compact Pulsed Hadron Source*

Cheng Cheng[#], Du Taibin, Guan Xialing

Department of Engineering Physics, Tsinghua University, Beijing 100084, China

Key Laboratory of Particle & Radiation Imaging (Tsinghua University), Ministry of Education

Key Laboratory of High Energy Radiation Imaging Fundamental Science for National Defence

Abstract

Compact Pulsed Hadron Source (CPHS) system has been developing by the department of engineering physics of Tsinghua University in Beijing, China. Up to now, conceptual design and engineering design of CPHS have been completed. Accelerator of the CPHS consists of an Electron Cyclotron Resonance (ECR) proton source, a Low Energy Beam Transport (LEBT), a 3 MeV radiofrequency quadrupole linac (RFQ), a 13 MeV drift-tube linac (DTL), and a High Energy Beam Transport (HEBT). In design of our RF power source, both RFQ and DTL share a single klystron which is capable of 3.0 MW peak RF power and a 3.33% duty factor. Portions of the RF power system, such as pulsed high voltage power supply, modulator, crowbar protection and RF transmission are all presented in details in this paper.

INTRODUCTION

Recognizing the usefulness of compact hadron source, Tsinghua University has launched a project of realizing a Hadron Application and Technology Complex (HATC). The initial phase of the HATC is called the CPHS^[1]. The goal of CPHS construction is to promote the exploratory research of scattering methodology, the education of using protons and neutrons at the universities, the industrial applications, the medical use of hadron therapy and radiography, and accelerator-driven subcritical-system (ADS) facilities. The CPHS comprises a 13 MeV proton accelerator, a neutron target station, and some experimental stations. The CPHS's accelerator is made up of five main parts which are an ECR proton source^[2], a RFQ^[3], a DTL^[4], radiofrequency (RF) power source and beam transport^[5]. This paper introduces the major technical design of the RF power source for the CPHS.

TECHNICAL DESIGN OF RF POWER SYSTEM

In design of our RF power system, both RFQ and DTL share a single klystron which is capable of a maximum output peak RF power of 3.0 MW at a 3.33% duty factor. RF power from the klystron is distributed by a power splitter with a ratio of 1:2. About 0.7 MW RF power is coupled into RFQ, and 1.4 MW power or so is sent to DTL. The RF power system consists of a signal generator,

an exciting amplifier, a klystron, pulsed high voltage power supply (PHVPS), a modulator, crowbar protection device, and RF transmission subsystem. Fig. 1 is the block diagrams of RF power system.

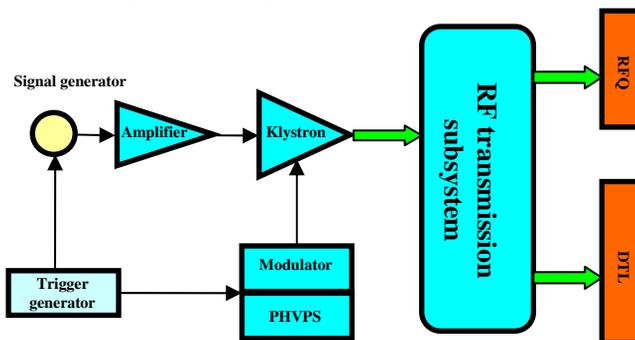


Figure 1: Block diagrams of RF power system.

PHVPS

The PHVPS for the RF power system was designed by using a creative and simple electric circuit, which achieves the purpose of converting AC power into DC power then into pulsed power simultaneous. Fig. 2 is the electric schematic of PHVPS.

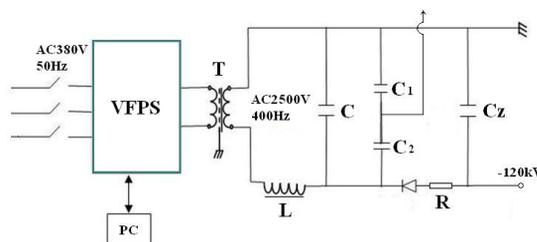


Figure 2: Electric schematic of PHVPS.

PHVPS consists of a variable-frequency power source (VFPS), a driver transformer (T), a LC resonant circuit, a rectifying circuit and an energy-storage capacitor (Cz). VFPS converts three-phase AC power (50Hz) into single-phase AC power at a frequency of 400Hz. The voltage of 400Hz AC raises to 2500V through the driver transformer, at the same time the LC resonant circuit and the rectifying circuit charge the energy-storage capacitor

*Supported by the “985 Project” of the Ministry of Education of China.
#chengch@mail.tsinghua.edu.cn

up at a voltage of 120kV. Subsequently, DC power is converted into pulsed power by operating modulator switch.

Klystron

As far as high-power RF (either peak power or average power) was concerned, klystron was a reasonable choice as the RF power generator for the CPHS project which requires over 2.1 MW of peak power for 0.5 ms H+ pulses at a beam duty factor of 2.5%. At least 100 μs must be added to fill the DTL linac structure and to lock the control loops for the fields in the whole accelerator. Thus the RF power is applied for about 0.667 ms, and the RF duty factor is 3.33%. Table 1 lists the main parameters of the klystron.

Table 1: Specifications of Klystron

Parameter	Minimum	Normal	Maximum	Units
Operating Frequency	324	325	326	MHz
Output Peak Power	0.5	2.5	3.0	MW
Output Average Power			100	kW
Duty Factor		3.33		%
RF Pulse Width		0.667		ms
DC Pulse Width		0.725		ms
DC to RF Efficiency	55	58		%
Beam Voltage		108.5	110	kV
Beam Current		48.9	50	A
RF Power Gain	52	53		dB

Modulator and Crowbar Protection Device

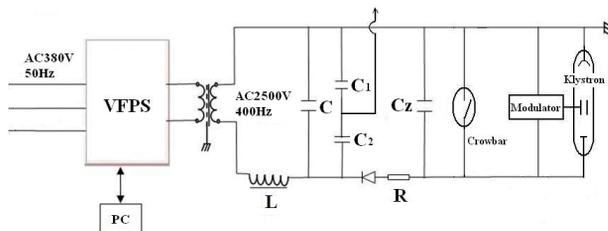


Figure 3: Overall power supply for klystron.

Figure 3 is an overall electric schematic of power supply for klystron. It is shown that PHVPS equipped with a crowbar protection circuit supplies the klystron's cathode with a DC high voltage of -108.5kV. A floating-

deck modulator is used for modulating anode voltage of the klystron. The 2.5-MW klystron would operate at a beam voltage of about 110 kV for 58% efficiency. This klystron voltage is in the optimum range for a modulation anode floating deck modulator. The anode pulse voltage is generated by switching the cathode voltage through dividing resistors in the modulator. The anode voltage can be adjusted by the dividing ratio of the resistors, and the pulse duration is controlled by switching device connected with the resistors in series [6]. FET is adopted as a semi-conductor switching device because the required switching current is about 1 A. Figure 4 is the electric schematic of modulator.

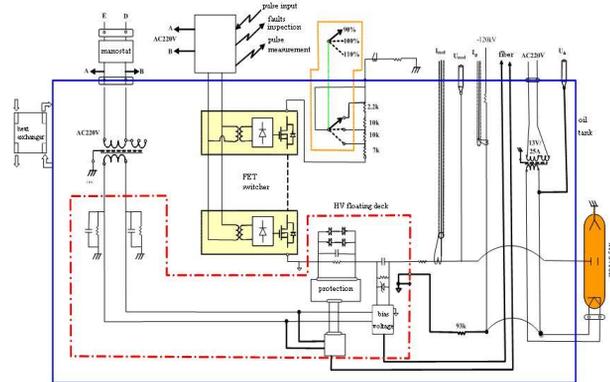


Figure 4: Electric schematic of modulator.

The crowbar circuit is applied for protecting the klystron at the spark event. In the crowbar circuit, 4-series ignitron configuration is adopted, which withstands a high voltage more than 120 kV. More than 7,500 A current flows through the 4-series ignitron when crowbar is operating at discharge, at the same time about 6 joules energy in the klystron and DC capacitor bank is dissipated within 6μs.

Transmission Subsystem

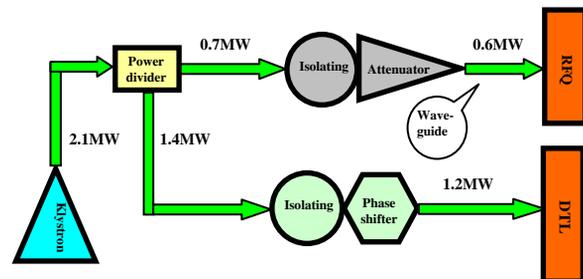


Figure 5: Block diagrams of RF transmission subsystem.

For the 2.5-MW klystron, the reflected power levels are at a damaging level due to the higher forward power, so the RF transmission subsystem requires a safety and stability design. RF transmission system consists of a power divider (power ratio of 1:2), an isolating attenuator, an isolating phase shifter, and some waveguides. As shown in Fig. 5. The isolating attenuator is made up of a

4-port circulator, a Y-junction, a high power load and a sliding short. It can be adjustable for amplitude from 100% to 80% to meet the 0.6 MW power need of the RFQ. The isolating phase shifter is a similar setup of a circulator where a sliding short is connected to port 2 of the circulator. Changing the position of the sliding short the phase of the output RF can be adjusted for a phase range by $\pm 45^\circ$. This setup will supply stable power split in the power divider and protection of the klystron against any reflections.

CONCLUSIONS

The conceptual design of RF power system has finished since Dec. 2009. The engineering design of it was completed in April 2010. Now, amplifier, PHVPS, klystron, modulator and crowbar protection device are in developing and manufacturing stage. The whole system will be assembled in Tsinghua University in Aug. 2011.

REFERENCES

- [1] Wei. J, Chen. HB, Cheng. C, et al, The Compact Pulsed Hadron Source: A Design Perspective. 13th International Conference on Accelerator and Beam Utilization (ICABU), JOURNAL OF THE KOREAN PHYSICAL SOCIETY. 2010, 56(6):1928-1935
- [2] Z. Feng, X.L.Guan, et al, Design of the 2.45 GHz ECR Proton Source and LEBT in CPHS. Proceedings of this conference.
- [3] Q. Z. Xing, J.C. Cai, et al, Design of the CPHS RFQ Linac at Tsinghua University. Proceedings of IPAC10. 2010. 792~794
- [4] S. X. Zheng, et al, Research on Drift Tube Linac Model Cavity for CPHS. Proceedings of this conference.
- [5] G. H. Li, et al, Design of the HEBT for CPHS. Proceedings of UCANS-I conference.
- [6] H. F. Ouyang, et al, The High Intensity Proton Linac For CSNS. Proceedings of this conference.