RF POWER GENERATION SYSTEM FOR NFZ ELECTRON LINAC

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Abstract

This paper describes the performance and architecture of the RF power generation system of the NFZ series small-size Linac, which is developed for multipurpose irradiation application. The RF power system supplies 3 MW peak power, 6 μs RF pulse. The average RF output power is more than 6 KW, which is a key factor determining the accelerator beam power. This system is consists of three parts: (1) an all-solid state RF driver with adjustable output RF frequency (2855-2857 MHz) and power(20-70W); (2) a line-type power pulser with a series triode command charging regulator and a energy recovery device; (3) a high output average power multicavity klystron.

One year operational results are presented.

1 INTRODUCTION

NFZ series electron Linac has been developed at Nanjing University for multipurpose irradiation. In order to realize this goal , the series electron Linac is required with wide energy range(4-12 Mev) and high average beam power (~3kW). The now available S-band magnetron is not able to meet the beam power requirement . Furthermore, high-power magnetron has short service life and poor frequency stability. So a multicavity klystron is used as RF amplifier to construct RF power generation system.

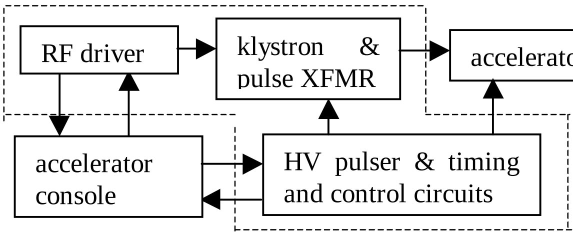

Fig.1 RF power generation system and its interface with accelerator

The system architecture and interface with accelerator are shown in Fig.1.

As can be seen from Fig.1 the RF generation system consists of three parts: an all-solid state RF driver , a HV pulser and a klystron. The HV pulser provide two HV pulses, one for the klystron and another for the accelerator electron gun. The RF system operation includes RF frequency and power adjustments with local or remote control.

2 SYSTEM DESCRIPTION

2.1 Klystron and pulse transformer unit

This unit consists of a klystron with its solenoid focusing magnet and a 9.2:1 pulse transformer. The electron gun of the klystron is immersed in transformer oil for insulation, cooling and short connection with the pulse transformer. The unit is movable, if necessary, for convenient installation and transportation.

Table 1
IEAS KS-59 klystron parameters

Operating frequency	2854-2857 MHz
Peak output power(max)	3 MW
RF output average power(max)	>6 kW
RF pulse width(max)	7 μs
Beam voltage(max)	110 kV
Beam current(max)	74 A
Efficiency	>37%
Saturation gain	>50 db
Phase modulation	<10^{o} (1%)

The main characteristics of KS-59 klystron developed by IEAS are shown in table 1.

The pulse transformer has a quartet secondary winding [1] of which one bifilar winding provides a HV pulse for the klystron and another one delivers a pulse voltage of ~60 kV to the accelerator bombarding electron gun(~2 kV bombarding voltage). The twin bifilar winding construction is favorable for small-size accelerator to obtain good HV pulse waveform and decrease the RF power generation system size.

2.2 Pulser

The line-type pulser was designed and developed to power the KS-59 klystron over a large operating range with providing variable PFN charging voltage and pulse repetition frequency. The goals for the RF power system were to design and fabricate a robust , highly regulated system capable of operating at variable peak and average power levels. The table 2 gives the main specifications of NFZ series HV pulser.

Table 2
Specifications of the pulser

Pulse voltage(max)	>110 kV
Pulse current(max)	>74 A
Equi pulse width	8 μs
Flat pulse width	6 μs
Pulse rise time	≤1.5 μs
Pulse fall time	≤2.5 μs
Pulse repetition rate(max)	>500 Hz
Pulse amplitude deviation	≤±0.5%
Pulse amplitude drift	≤±0.3%

The series triode command charge regulator consists of the primary power, charging transformer with a energy recovery device, series triode and PFN. The start-up of the triode is determined by the starting pulse from the timing circuit and causes energy from the primary power to charge up the PFN. Hence, a proper delay of the starting pulse, following the master trigger pulse, is favorable for high PRF in order to prevent the master thyratron from breakdown accident. The cut-off of charging current depends on the preset charge on the PFN or the required klystron pulse voltage.

It should be noted that no shunt or chipping diode is required in such a charging regulator.

The energy recovery device at the charging transformer secondary is to return the energy stored in the charging transformer to the power supply while the series triode cut the charging current in order to maximize efficiency. A special designed all-solid pretrigger is used to turn on and off the charging triode.

The PFN is a Guillemin E-type network which consists of 15 equal-valued capacitors(0.0133 μF each) and a continuously wound, tapped coil whose physical dimensions are chosen so as to provide proper mutual coupling at each mesh capable of obtaining a required pulse flatness. The impedance of PFN is 20 Ω which is decided by the load impedance reflected to the primary side of the pulse transformer at the maximum operating voltage.

2.3 Timing Unit

The timing unit provides several timing pulses for the HV pulser and accelerator control racks, including:

- The master thyratron trigger pulse(MTP)
- The charging triode starting-up pulse(CSP)
- The charging triode turn-off pulse to protect the klystron from excessive beam voltage in case the charging regulator is out of order(CTP)
- The RF driver trigger pulse(DTP)
- The sync pulse for accelerator control(SP)

In Fig.1 are shown the timing relations between these pulses and triode charging current cut-off pulse(CCP) of which the time is determined by the required klystron pulse voltage.

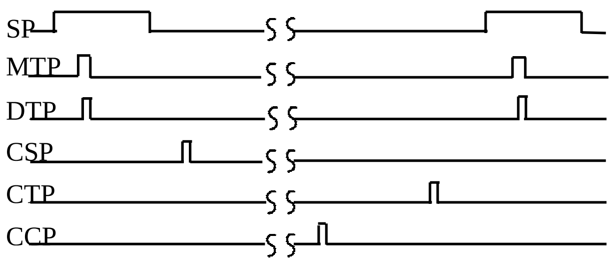

Fig.2 Schematic relations between pulses from the timing circuit and the charging current cut-off pulse(CCP) from the triode pre-trigger

It can be seen from Fig.2 that the DTP is little latter than MTP. This delay time is adjustable to make the RF driver pulse located in the HV pulse flat and obtain a stable and satisfactory RF power pulse waveform.

The sync pulse leads the MTP by 20 μs in order to realize accelerator automatic beam current control and stabilize its output beam current.

2.4 Control and interlock protection circuits

Depending on a control key lock setting , the pulser could be controlled from either a local manual panel or a remote manual panel at the accelerator operator console.

In order to protect the klystron modulator and other accelerator parts, there are a number of conditions which can not be allowed to occur , or should they emerge, must be promptly terminated. Some main points are

- Solenoid undercurrent - In order to ensure that the klystron beam is properly focused, HV pulse should not be applied if solenoid undercurrent emerges.
- Inadequate cooling - Cooling includes airflow for the HV pulser and liquid cooling for the klystron. A airflow protective interlock is normally included to turn off the low-voltage supplies and beam voltage supply if the blowers cease to operate. The water cooling is invariably necessary for the klystron collector and drift tube and its solenoid. The klystron beam voltage must be removed first if the cooling liquid is not enough , then the coil power supply must be shut off as soon as possible.
- Excess body current - The body current exceeding 40 mA average will trip out its overcurrent relay to shut off the beam power supply.
- Excess HV current - While it emerges, probably due to HV pulser self or also klystron, the HV DC supply will be cut off.
- Excess RF reflected power - It is not allowable, otherwise the excess reflected power will crack the RF output window of the klystron. A back-power coupler is arranged for waveguide-arc protection. If the back-power increases to an excessive level, a relay contact will be used to turn off the beam power supply.

In order to ensure the klystron, HV pulser and accelerator normally operating, the vacuum interlock must be included for the klystron, RF transmission system and accelerator. In addition, the HV pulser must incorporate the door interlock for operating safety and maintenance, and thyratron untriggering interlock for stability in use.

2.5 All-solid state RF driver

On the basis of the requirements of the KS-59 and accelerator, there are the following main technical parameters for the RF driver listed in table 3.

Table 3
RF driver technical parameters

RF operating range	2855.5-2857.5 MHz
Step size for RF frequency change	37.5 KHz
RF frequency stability	$<\pm 5\times 10^{-6}$
Output RF pulse width(variable)	6 μs
Pulse repetition frequency	determined by timing circuit
Output RF peak power(max)	70 W
Output impedance	50 Ω

The real RF operating frequency is determined with 8 different energy button on the accelerator control console of which each can be regulated independently with its state code, that is, the different state code controls remotely the RF frequency to meet the accelerator adjustment requirement.

The RF output power is changeable to make the klystron operating at saturation. The output power is regulated with changing the power supply voltage of the last amplifier (Fig.3), rather than with a variable attenuator as usual. Experiment has shown that its output power range is about 20-70 W which is good enough for the KS-59. It is also possible to change the RF pulse width according to actual requirement.

The schematic diagram of the all-solid state RF driver is shown in Fig.3.

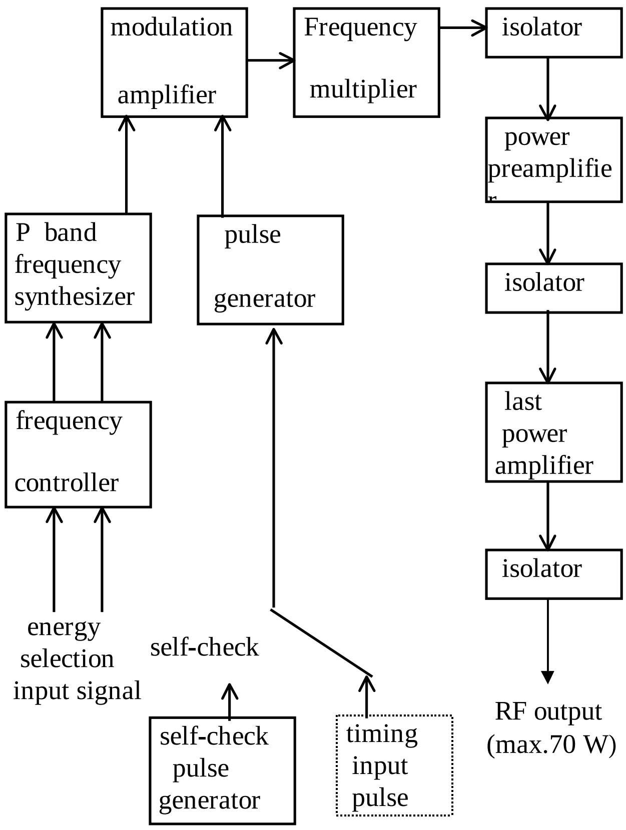

Fig.3 Simple schematic diagram of the solid-state RF driver

3 RESULTS

The first NFZ accelerator was completed in the early 1996, installed and put in use in a factory in the middle of the same year.

Most of troublesome problems for the RF generation system during testing period were associated with the HV pulser, including high pulse voltage and high pulse discharging current interference. Because interference signals may be transferred from one point to another by conduction or radiation, its reduction techniques include shielding, bonding, grounding and filtering, especially for the low-voltage supply, timing and control circuits, and two pretriggers.

More than one year reliable operation and good economical efficiency show that the RF generation system has a high degree of reliability and satisfactory performance. There were a small amount of accidents of the RF generation system of which the main cause is poor quality of individual circuit components. Only one time of the thyratron reservoir voltage adjust was needed during this period.

4 ACKNOWLEDGMENTS

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5 REFERENCES

[1] W. Feng: ‘Topology of pulse modulator output circuits used in small-size electron Linac’ Nuclear Techniques **20,** 438(1997), Chinese