DESIGN OF HIGH POWER PULSE MODULATOR FOR DRIVING OF TWYSTRON TUBE USED IN S-BAND LINEAR ELECTRON ACCELERATOR

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Abstract

This design related to an s-band linear accelerator that the main tube and buncher of it have been made. RF power supply is used in this accelerator tube made up of a Twystron with 2.5 MW peak power and frequency band width 2.9~3.1 GHz. This paper offers the design of modulator for this RF amplifier. This modulator design uses solid-state method and is under construction with specification of : Adjustable voltage from 0 to 120 kV, adjustable pulse width 2 until 7 micro second, adjustable repetition rate 80-120 Hz, ripple less than 0.25% and efficiency up 80 percent. This system designed with series of 6 modules that each of them provides 5 kV and IGBT switches that transform the voltage on the pulse transformer.

INTRODUCTION

A radio frequency linear accelerator is a device to accelerate electrons or charged particles in a linear trajectory. Depending on the kind of accelerator, the increment in the particle energy occurs in a RF electric field in synchronism with the passage of particles in the gaps of a coaxial system of cylindrical electrodes or in the electric field of an electromagnetic standing or travelling-wave induced in a waveguide. Fig.1 shows simplified block diagram of a travelling-wave linear electron accelerator.

Designing and manufacturing of a travelling-wave linear electron accelerator under supervision of Institute of Research in Fundamental Science and with corporation of Shahid Beheshti university is undergo for a period of time.

Since now main part of accelerator tube, buncher, electron gun, low power RF source and low and high power supplies is produced and RF lamp is prepared.

Next step in completion of this project is producing and transferring of high power microwave to the main tube. Production of high power microwave in this project is done with Twystron tube.

Designing and producing of power supplies, tube modulator and transferring high power microwave to the main tube of accelerator, is the most important part of this project. This paper is about design of modulator which is needed for driving electron beam from microwave tube. after proposing the problem we have mentioned explanation of different kind of modulators and at the end choosing of modulator type and also the design is offered. Fig. 2 illustrate the main part of tube and buncher.

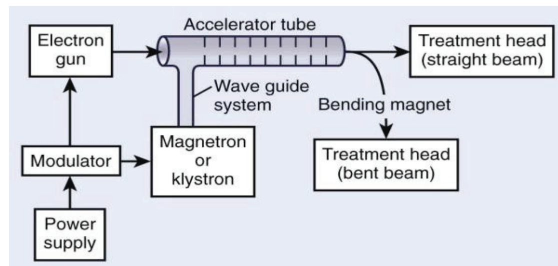
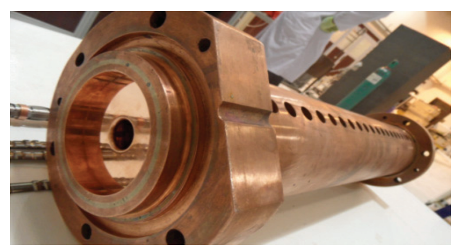


Figure 1: Simplified block diagram of travelling-wave linear electron accelerator.



(a)

Figure 2: Main tube of produced linear electron accelerator in Shahid Beheshti University [1].

PROPOSING OF PROBLEM

Different parts for designing RF power supplies needed for electron accelerator is divided to sub-systems which exact and simultaneous operation of them produces RF pulses with required power and pulse width and repetition frequency.

Finally this power is driven to the cavity with appropriate wave guides. Microwave amplifiers is divided to two groups of solid-state amplifiers and vacuum lamps.

Solid-state amplifiers dimensions are smaller than vacuum tubes and also the output current of them is higher but the advantage of microwave tubes is their higher output power in comparison with solid-state amplifiers [2].

Microwave tubes are used as oscillators or to boost the signal in the microwave frequency range.

These microwave tubes which are superior choice for high power, high frequency and wide-band applications are classified into two groups of linear-beam microwave tubes such as Klystron and Twystron, and crossed field tubes such as magnetron.

Klystron tube is one of the most applicable devices for amplifying RF signal which can prepare multi-megawatt power in its output. this tube are inherently narrowband, but can be work pulsed or continuously. Characteristics of TWT tube is near to klystron but with difference that klystron has advantage of high power and limitation in band-width and TWT has wide band-width and limited power [3].

Twystron lamp is a combination of this two tubes which has wider band-width in compare with Klystron and higher power in compare with TWT. We choice Twystron tube in this project because of our requirement to high power and wide bandwidth. The proper tube for this project is prepared which its properties are mentioned in Table 1. Fig. 3 shows systems which is needed to drive this tube.

Table 1: Twystron Tube Properties [1]

parameter	Value
Peak power	2 MW
Pulse duration	7 µsec
Output pulse frequency	100 HZ
Frequency range	2.9-3.1 GHz

In linear-beam tubes, a voltage applied to an anode accelerates electrons drawn from cathode, creating a beam of kinetic energy. power supply potential energy is converted to kinetic energy in the electron beam as it travels toward the microwave circuit.

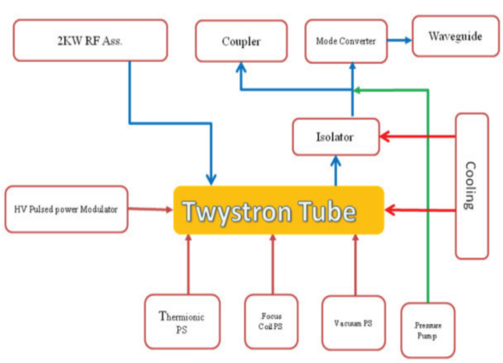


Figure 3: Systems which is needed to drive Twystron tube.

A portion of this kinetic energy is transferred to microwave energy as RF waves slow down the electrons. remaining beam energy is either dissipated as heat or returned to the power supply at the collector. Because electrons will repel one another, there is usually an applied magnetic focusing field to maintain the beam during the interaction process. the magnetic field is supplied either by a solenoid or permanent magnets. Fig. 4 shows a simplified of linear-beam tubes [4].

In high power microwave Tubes like Twystron it is needed that modulated pulse be produced by an modulator and be applied to cathode of Tube.

Therefore, in the rest of this paper we discuss various methods of building modulators and at the end, the appropriate method is recommended.

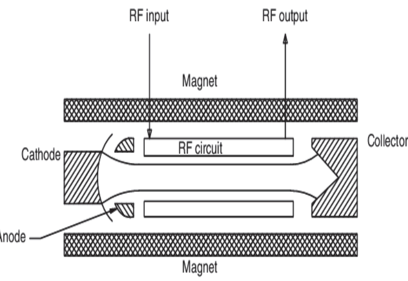


Figure 4: Schematic diagram of a linear beam tube [4].

REVIEW OF MODULATORS

Generally power modulator refers to a system which is responsible for producing square pulses with high power and specific repetition rate.

The main idea in production of high power pulses following as storing of energy in an electrical energy store and releasing it very fast.

The output pulse of modulator must have sharp rising and falling edges and smooth surfaces.

According to technological level, modulators can be divided into two categories: classical and modern.

This division is based on the way of progress (evolution) of modulators and it doesn't show any special advantages.

Classical Modulators

It's divided to two groups concluding: 1-Hard Tube or Vacuum Tube Modulators and 2-Line-Type Modulators.

In Hard Tube Vacuum Modulators storage energy in a capacitor bank is applied directly in a microwave lamp. The switch which is used in this modulators is a kind of vacuum lamp and because of this, they are known as Vacuum Tube modulators. Figure 5 shows general figure of fundamental circuit of Hard Tube Modulator.

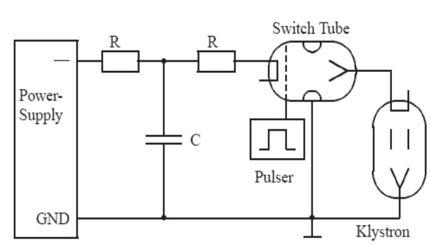


Figure 5: General figure of fundamental circuit of Hard Tube Modulator.

In this modulators discharge mode in the time of connection or disconnection is controlled by switch and because of that output pulses has a smooth surface and proper rising and falling edges.

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In quasi-linear modulators a Pulse Forming Network act as energy storage component and a fast switch like spark gap act as a switch.

Advantages of these modulators are relative simplicity in design and construction and the possibility of using various switches (spark gap, and semiconductor and Tayratrun). But one of the major defects of this type modulators, despite their relative simplicity is their low quality output pulses. Table 2 summarizes the comparison between hard-tube modulators and quasi-linear modulators.

Table 2: Comparison between Two Types of Modulators

PARAMETERS	Hard Tube	Quasi-linear
efficiency	Lower	higher
Pulse shape	High-grade	Low-grade
Change the pulse duration	easy	difficult
Complexity of circuit	more	less

Modern Modulators

This section describes modulators with semiconductor switches and Marx-Type modulators as most modern modulators. The main advantage of modulators with semiconductor switches is achieving high Pulse Repetition Rates (up to 10kHz) and Marx generator is an intelligent method to produce high voltage pulses using sources with small amplitude but flatten the pulse of Marx generator requires increasing energy and volume of modulator and using protective circuits that increase costs and reduce the output pulse repetition rate.

MODULATOR DESIGN

In order to choose the optimal method for making the appropriate modulator, at first the required specifications of selected Twystron Tube must be mentioned. Table 3 shows these properties.

Table 3: Required Properties for Modulator

Character	value
Pulse repetition rate(Hz)	80-120
Pulse duration(μs)	2-7
Maximum output current (A)	72
Maximum output voltage (kV)	120

To provide this modulator, its sub-systems must be design simultaneously which conclude: AC to DC convertor, charging set, pulse transformer and pulser set [5]. In this design we have used switching power supply as AC to DC convertor and charger set.

This part consists of six series 5kV modules that each consists of five 1kV SMPS technology modules plus one power factor corrector module which are series together and results 30kV DC power supply. an IGBT power switch bank transfer energy of this PS into primary of a step up pulse transformer with 1:4 ratio which finally generates adjustable voltage up to 120-kV pulser collection consist of series IGBT that can be control and adjust the pulse repetition rate and pulse duration.

DISCUSSION AND CONCLUSION

Studies show that the method of using SMPS modules and using series of them to provide a several kV module and discharging it to primary side of a pulse transformer is one of the best method of manufacturing modulators.

This method in addition to its easy maintenance due to the modularity, has other advantages such as: efficiency above 80% through the use of switching power supplies and low volume.

Explained modulator will be have flat type pulses with ripple less than 0.25% and very short rising and falling time and without structural changes, the output pulse width can be change between 2 to 7 microseconds and pulses frequency can be changed between 80-120 hertz.

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