Neutron generator for the array borehole logging*

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Abstract The performance mechanism of the array neutron generator to be used to porosity logging is presented. The neutron generator utilizes a drive-in target ceramic neutron tube, which bursts neutron with fast-slow period selectively pressure. Regulation of the neutron tube is accomplished by pulse width modulation. The high voltage power supply is operated at optimum frequency.

Keywords Neutron logging, Neutron generator, Pulsed neutron techniques

1 Introduction

The neutron generator is applied to a new neutron porosity logging tool(APS), the detecting part of which includes five high efficiency ^{3}He tubes arranged as array. The four of them are used to detect epithermal neutron, and the rest one is used to detect thermal neutron. Because of utilizing the pulsed neutron generator, the harm related to a radioactive isotope neutron source is overcome, the following measurements can be carried on: epithermal neutron slow-down time; formation capture cross section Σ; epithermal neutron attenuation time; the epithermal neutron count ratio in the two kinds of source space; the space between logging tool and borehole casing and so on. With these measurements and handling techniques, vertical distinguishability is improved, the effect of space between the logging tool and borehole casing is cut down, the more precise porosity can be given. But, the pulsed neutron generator with this measurement method requires a higher neutron yield, emitting neutron with fast and slow period, which can emit 30 neutron bursts with 10μs width in the 1200μs and 1 neutron burst with 100μs width in the 800μs.[1,2] According to this pattern, we develop this new neutron generator.

2 Major specifications of neutron generator

(1) Emitting 14 MeV fast neutron, neutron yield being larger than 4×10^8n/s.

(2) There are two operating modes in one neutron pulse period: 10μs/30μs$\times$30+100μs/700μs$\times$1. This means neutron pulse sustaining duration/pause time $\times$ pulse numbers.

(3) In a continuous operation for 4 h, the change in neutron output yield is less than five percent.

3 Configuration of the neutron generator and circuit principle

The neutron generator includes a special ground and regulated power supply, and an under well neutron generator. The latter consists of a neutron tube and a high voltage multiplier, both of which are installed in a 74mm diameter sealed stainless steel tube, which is filled up with dimethyl silicon oil. Expanding-proof method is adopted here. The control circuit is installed on the two sides of the "I" shape frame. The electric circuit diagram is given in Fig.1. There are an ion source control circuit, a reservoir control circuit, a target electrode DC-AC converter and a high voltage multiplier in the borehole part.

4 Neutron tube

Neutron generator utilizes a NT503(50mm in diameter) drive-in target ceramic neutron tube, which includes a cold cathode Penning ion source, a mixed deuterium-tritium reservoir and a drive-in target. When neutron generator operates, the mixed deuterium-tritium gas will be released by heating the reservoir. Deuterons

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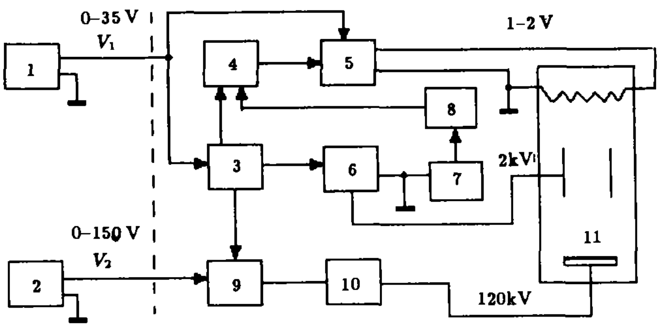
and tritons produced in the Penning source are accelerated and bombard the target to produce neutrons with an energy of approximate 14 MeV. Neutron tube exhaust is finished by high temperature exhausting technology, which gets the optimum condition. Neutron output is maintained at a stable state by replenishing the target with a mixed deuterium-tritium beam. The lifetime of neutron tube is relatively long and exceeds 400 h. The neutron tube can be stably operated at up to 150°C.



1,2 Ground adjustable voltage power supply;
3 Regulated voltage circuit;
4 Pulse width modulation;
5 Reservoir converter;
6 Ion source controlling circuit;
7 Sampling;
8 PI regulating;
9 DC-AC converter;
10 High voltage multiplier circuit;
11 Neutron tube

Fig.1 The circuit diagram of neutron generator

5 Ion source controlling circuit

Ion source controlling circuit is utilized to form about 2 kV anode pulsed voltage, the circuit diagram is given in Fig.2. The oscillator gives a square waves with 40μs period and a monostable multivibrator I gives a pulse voltage with about 30μs width, which are input into an analogue operation amplifier10-5. When the 31st pulse arrives, R-S trigger transfers to low electric level, the fast operating mode is ceased, a monostable multivibrator II, which can be used to adjust delay interval between fast and slow operating mode, triggers at the same time. Pulse width is about 30μs. The third monostable multivibrator produces a pulse with about 100μs pulse width. When the 51st pulse arrives, the R-S trigger returns to the higher level, the slow operating mode is ceased and the fast operating mode is resumed. The anti-excitation converter using BG_1 as the core gives 2 kV fast pulsed voltage, a positive-excitation converter using BG_2 as the core gives 2 kV slow pulsed voltage. A set of pulse being composed by passing through a diode or gate circuit supplies to the ion source anode, the timing sequence is shown in Fig.3.

Magnetic current of the anti-excitation converter composed of the BG_1 is in the continuous state, which means that transformer secondary coil current and transformer magnetic flux to be larger than zero before the BG_1 is ceased, the output voltage is:

$$V_{o1} = n_1[\delta_1/(1-\delta_1)]V_1$$

where V_1 is an applied voltage, $\delta_1 = t_{on}/T$ is the duty factor of the fast pulse, n_1 is the coil ratio of the transformer T_1 [3], parameters of T_1 decide mainly the fast pulse fall-time which is less than 3μs. An output voltage of positive-excitation converter consisting of BG_2 is $V_{o2} = n_2\delta_2V_1$, where n_2 is the coil ratio of the transformer T_2, δ_2 is the slow pulse duty factor. The two output voltage amplitudes can be the same by changing th eparameters related to V_{o1} and V_{o2}.

6 Reservoir controlling circuit

The operation of the reservoir demands about 1-2V voltage and 1 A heating current, which controls the gas pressure within the neutron tube. The reservoir controlling circuit utilizes a set of alone excitation converter circuit for producing an unsine wave heating current and the same power supply with the ion source, which is not stationary voltage. The methods for controlling heating current have two ways: one is manual control by changing supply voltage V_1 on the ground; the other is automatic control under well, using pulse width modulation. Automatic adjustment under well can be accomplished by changing the surface power supply voltage within 5 V.

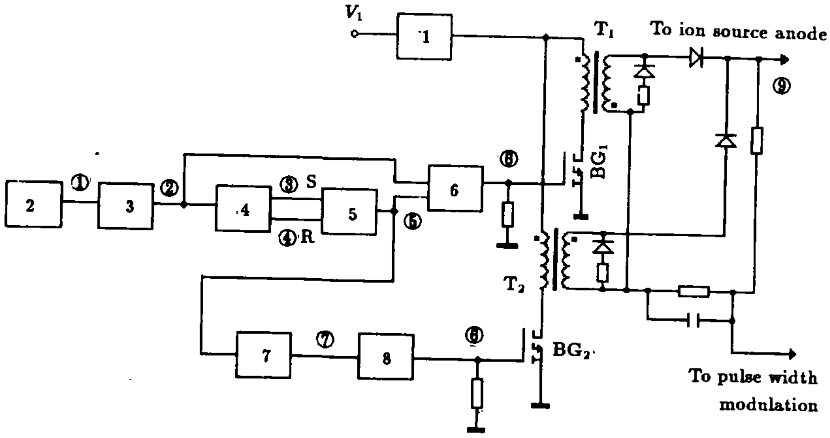


Fig.2 The principle diagram of ion source anode controlling circuit
1 Regulated voltage circuit; 2 25 kHz oscillator; 3 Monostable multivibrator I; 4 Analogue operation amplifier; 5 R-S trigger; 6 NAND gate and negative buffer (fast style); 7 Monostable multivibrator II; 8 Monostable multivibrator III

(1) 25 kHz oscillator;

(2) Monostable multivibrator I output;

(3) Set 1 pulse;

(4) Set 0 pulse;

(5) Trigger output;

(6) Fast style driver;

(7) Delay single stationary state;

(8) Slow st le drive;

(9) 2 kV output

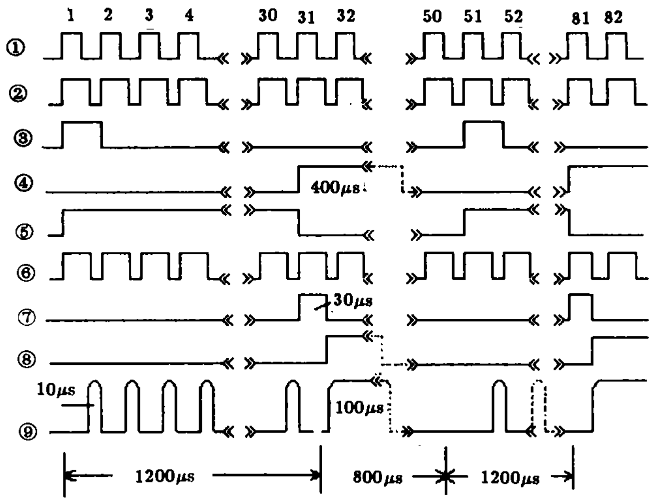


Fig.3 The timing sequence diagram of ion source anode controlling circuit

TL494 is utilized for modulating pulse width. Anode current modifies the duty factor of the pulse. The sampling signal from the returning circuit of the ion source anode is supplied to the error-amplifier of TL494 by proportional and integral regulation. The circuit diagram is shown in Fig.4. Because the process of releasing and absorbing gas lags obviously behind the change in electric current, the integral time constant of PI regulation is about 30s.[4]

7 Target electrode high voltage circuit

The independent excitation push-pull circuit is adopted for DC-AC converter, the two way mode is adopted for high voltage multiplying rectifier circuit. The ion beam is pulsed because of pulsing operation of ion source. When the pulse occurs, the pulse ion beam current is 4-8 times of the average beam current (the duty factor of fast and slow pulse is 1/4 and 1/8, respectively). While the ion beam current occurs, the capacitors in the multiplying circuit are discharged. The effective output voltage of the multiplier descends. This time is for emitting neutron. If the high voltage descends too much, it might decrease the neutron yield obviously, the smaller the internal resistance of high voltage power supply, the better it would be.

The internal resistance and frequency features of this circuit have been studied experimentally.[5] It can be seen from Fig.5 that, in the pairs of curves there are the same input voltage and different load, for example curve(1) and curve (2), or curve (3) and curve(5).

In some frequencies the curve is close and others are distant. The part of distant curves corresponds to the frequency with relatively larger internal resistance, and the close part corresponds to the frequency with relatively smaller internal resistance. The experimental results show that neutron generator would give the largest neutron yield while operating at the frequency of 2.0~2.5 kHz.

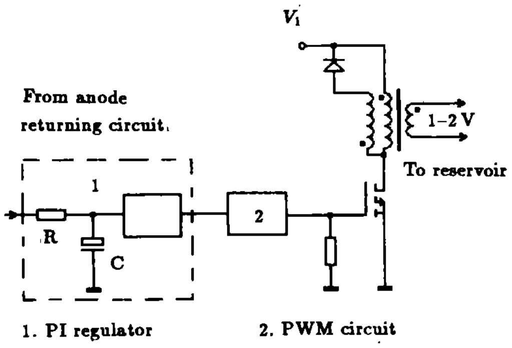


Fig.4 Reservoir controlling circuit

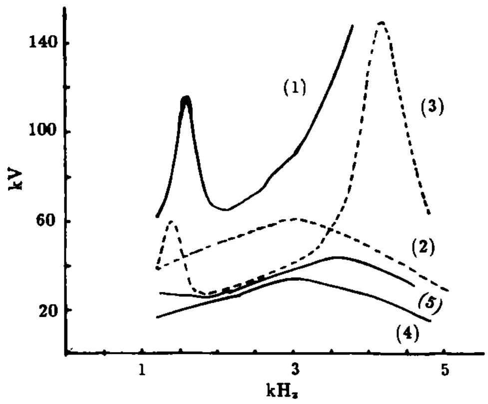


Fig.5 The frequency characteristic curves with the different loads

(1) V_i=70 V, R_L=3000 MΩ; (2) V_i=70 V, R_L=230 MΩ; (3) V_i=30 V, R_L=3000 MΩ (4) V_i=30 V, R_L=230 MΩ (5) V_i=30 V, R_L=460 MΩ

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