Study of the pulsed working characteristics of the penning ion source for neutron tubes

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Abstract The pulsed working characteristics of the neutron tube ion source were studied experimentally. The principle and method of selecting the gas pressure and anode voltage were determined.

Keywords Anode voltage, Pulse width of discharge current, Pulse width of neutron, Carbon/Oxygen(C/O) spectral logging for petroleum

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1 INTRODUCTION

The cold cathode penning ion source is usually used in sealed neutron tubes because it has the advantages of simple structure, low electric power consumption, long operating life, working at low gas pressure, etc. The penning ion source operates in a state mainly determined by the following factors such as structure of ion source, magnetic induction intensity and its distribution, anode voltage and internal gas pressure. In a neutron tube, the first two factors are fixed and the last two factors are changeable. Whether the neutron tube emits continuous or pulsed neutrons depends on the mode of anode voltage, DC or pulsed. In this paper, some characteristics of the ion source in the pulsed mode were studied through the experiments.

2 STRUCTURE AND EXPERIMENTAL CIRCUIT OF THE ION SOURCE

A ceramic neutron tube of model NT501 with a driven-in target is used in the present experiment. The ion source has a structure as shown in Fig.1.[1] The inner dimension of the anode cylinder is $\phi 20\,\mathrm{mm} \times 10\,\mathrm{mm}$ and the inner dimension of the cathode cap is $\phi 38\,\mathrm{mm} \times 22\,\mathrm{mm}$. The column permanent magnet (3 in Fig.1) forms an inhomogeneous magnetic field. The intensity of magnetic induction is 0.27 T at the center of the magnet surface and 0.14 T at 1 cm from the magnet surface in the axial direction.

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The experimental circuit is shown in Fig.2. In the experiment, first, an anode pulse voltage was applied to the neutron tube, then the heating voltage of the deuterium-tritium reservoir was increased to release gradually the deuterium-tritium gas which was ionized at certain pressures to produce discharge pulses and the target electrode of the neutron tube did not produce neutrons without high voltage applied to it. In Fig.2, V_1 is used for measuring the heating voltage of the deuterium-tritium reservoir, V_2 for measuring the average discharge current, and the dual trace oscilloscope for measuring the voltage pulse waveform and the pulse triggering and quenching time. High voltage was not applied to the target electrode of the neutron tube.

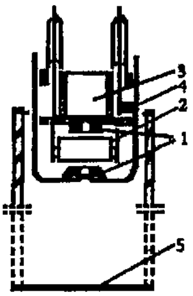

Fig.1 Structural scheme of the ion source for the neutron tube
1 Cathode, 2 Anode, 3 Magnet, 4 Reservoir, 5 Target

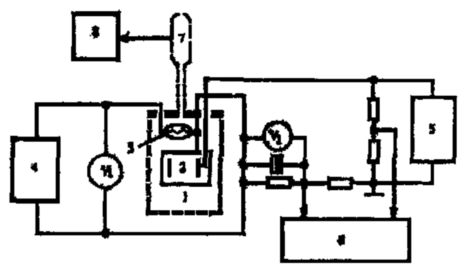

Fig.2 Experimental circuit
1 Neutron tube, 2 Ion source, 3 Deuterium-tritium reservoir, 4 Heating power supply for the reservoir, 5 Power supply for the anode, 6 Dual trace oscilloscope, 7 Vacuum gauge, 8 Vacuometer

3 EXPERIMETAL RESULTS

3.1 Trigger delay characteristics

When an anode voltage is applied to the ion source at a certain gas pressure, the trigger time for electric discharge is always later than the starting time of power-on for a time interval, called the discharge trigger delay time, whose magnitude is at the microsecond level, which can be ignored in the DC operating mode. In the operating mode of high frequency pulse, due to the existence of discharge delay time, the trigger time of electric discharge always lags behind the starting time of voltage in a voltage period. The discharge current reduces nearly simultaneously to zero as the anode voltage reduces. So, in a voltage pulse period, when the pulse width does not change, the discharge current has a smaller pulse width than the voltage. The delay time influences the discharge current pulse width, the average discharge current, and the neutron yield.

Fig.3 shows the relations between the peak anode voltage and the delay time at different pressures. The period of the anode pulse voltage used in the experiment is $50\,\mu s$, the bottom pulse width is $14.7\,\mu s$ and both the rising and falling edges are $1.8\,\mu s$. It is seen from the curves in Fig.3, that with the same anode voltage, while the gas pressure increases, the delay time decreases and so the discharge current pulse width increases. This time span is affected mainly by such factors as the rise time of pulse front edge, the pulse peak value, and the gas pressure, because these different conditions lead to different electric field intensities, different average free paths of the electrons, and different times needed for self maintained discharge. When the pressure is too high, the discharge is instable. Therofore, decreasing the delay time by resorting to the increase of the gas pressure is limited.

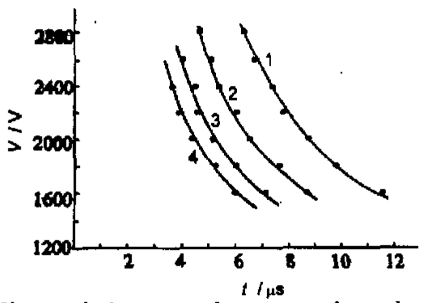

Fig.3 Relation curves between peak anode voltage and discharge delay time at different pressure
1 0.8Pa, 2 1.2Pa, 3 1.33Pa, 4 1.6Pa

3.2 Volt-ampere characteristic curves

The characteristic curves of different peak voltages and discharge currents at different pressures are given in Fig.4 and Fig.5. Fig.4 shows the DC mode while Fig.5 shows the pulse mode in which the current is an average discharge current. Comparing the curves in Fig.4 and Fig.5, it is seen that (1) to get the same discharge current both in the DC mode and in the pulse mode, the neutron tube sould work within two different gas pressure ranges; (2) in the DC mode, meandering occurs in a certain section of the characteristic curve, which means an unstable working region, whereas in the pulse mode, the meandering does not occur; (3) with rising in the anode pulse peak value, the average discharge current increases more slowly in the pulse mode than in the DC mode mainly because in the pulse mode the instantaneous discharge current is several times higher than the average discharge current (associated with the duty ratio). Hence, due to an increase in both the internal resistance of the pulse source and the equivalent resistance of the ion source, the anode voltage rise has a less powerful effect on enhancement of the neutron yield than in the DC mode.

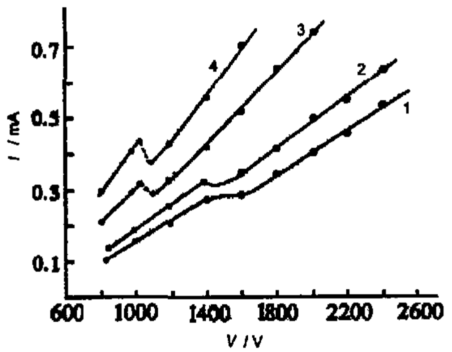

Fig.4 $V-I$ curves in the state of direct current
1 0.12 Pa, 2 0.133 Pa, 3 0.2 Pa, 4 0.227 Pa

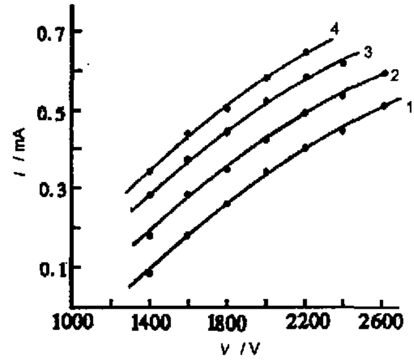

Fig.5 $V-I$ curves in the pulsed state
1 0.8 Pa, 2 1.2 Pa, 3 1.33 Pa, 4 1.6 Pa

3.3 Relations between the heating voltage of the deuterium-tritium reservoir and the gas pressure in the ion source

Changing the heating voltage of the deuterium-tritium reservoir will lead to a change of the internal gas pressure of the ion source and the relations between them are given in Fig.6. It shows that a very small change of the heating voltage will cause a significant change of the gas pressure and the reservoir's heating voltage adoptesd is usually very low, so it is easy to realize the change of the gas pressure.

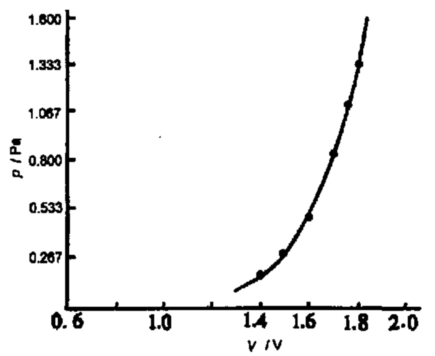

Fig.6 Gas pressure in the ion source as a function of the heating voltage of the deuterium-tritium reservoir

4 CONCLUSIONS

The ion source for the neutron tube has a much higher gas pressure when working in the pulse mode than in the DC mode. When the ion source for the neutron tube works in the pulse mode, an increase in the anode voltage or in the gas pressure results in earlier discharge triggering, leading to an increase in the discharge current pulse width and the average discharge current. In the pulse operating mode, the anode voltage rise leads to a less obvious increase in the discharge current than in the DC mode and to a decrease in the operating reliability, so the anode voltage should not be too high. Usually a fixed anode voltage is used and both the discharge current pulse width and average discharge current are changed by regulating the gas pressure.

On the occasion of the specified neutron pulse width, if the higher anode voltage is selected, the shorter voltage pulse width is selected. It follows the principle that the minimum pulse width of anode voltage is the sum of the neutron pulse width and the minimum delay time which can be searched out from Fig.3 after the peak anode voltage is determined.

When the peak anode voltage and the pulse width are both determined, the neutron pulse width is adjustable and the discharge triggering time can be changed within a certain range by regulating the gas pressure, when the quenching time for the discharge current pulse does not change.

5 EXAMPLE OF APPLICATION

It is needed for C/O spectral logging of petroleum that the pulse neutron emission frequency is 20 kHz and the pulse width is 6~8 μs, which can be adjusted to the maximum of 12 μs. The measurement of the gamma rays within a period is divided into two parts. The inelastically scattered γ rays are recorded in the first 15μs and the captured γ rays are recorded in the last 35 μs. The neutron pulse emission time is required to be set within the 15 μs inelastic gate. That is to say, the time spectrum of MCS pulsed neutron is required in a specified timing position.[2] Here two problems are put forward, one is the pulse width of neutron emission and the other is the starting time for neutron emission.

For example, the anode voltage is selected as 2000 V and the maximum working gas pressure 1.33 Pa, then we find from Fig.3 that the discharge trigger delay is 5.3 μs. In order to ensure that the pulse width of discharge current is 8 μs, the minimum time needed should be 13.3 μs. To improve the efficiency of the neutron tube and to prolong its service life, when the neutron yield decreases, the neutron emission time can be lengthened to 12 μs. At this time, the voltage pulse width (bottom) should be more than 17.3 μs. Ordinarily, the working gas pressure can also be lower and the discharge delay time may be increased to 7~8 μs. In this case, the voltage pulse width should be lengthened 2~3 μs or more. The starting time of the neutron pulse can be roughly regulated with a monostable circuit relating to its synchronous pulse, and then finely regulated by changing the gas pressure.

References

1 Wei B J, Zhong H M. Neutron tube and its application technology (in Chinese). Changchun: The Northeast Normal University Press, 1997, 38~42

2 Zhu D Z. C/O Spectral logging of petroleum (in Chinese). Beijing: Petroleum Press, 1984, 77~81