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(54) **An accelerator-type neutron source and a method of controlling the same.**

(57) An accelerator-type neutron source employs a target, an ionization section and a replenisher for supplying accelerator gas. A positive voltage pulse is applied to the ionization section to produce a burst of neutrons. A negative voltage pulse is applied to the ionization section upon the termination of the positive voltage pulse to effect a sharp cut-off to the burst of neutrons.

AN ACCELERATOR-TYPE NEUTRON SOURCE
AND A METHOD OF CONTROLLING THE SAME

This invention relates to an accelerator-type neutron source and a method of controlling the same.

Accelerator-type neutron tube sources are employed in many applications, such as in the radioactivity logging of wells penetrating subterranean formations. For example, in the art of neutron-neutron well logging a source of primary neutrons is employed to irradiate subterranean formations of interest and the resulting secondary radiation is measured by one or more detectors spaced axially from the source within the borehole. Such secondary irradiation may take the form of thermal neutrons, epithermal neutrons, or thermal neutron capture gamma rays. A logging tool for use in porosity measurements and including a neutron source and epithermal and thermal neutron detectors is disclosed in, for example, U.S. Patent No. 4,005,290.

In procedures such as porosity logging, the neutron source is a continuous source usually of a chemical type. Other well known radioactive well logging techniques involve the use of pulsed neutron sources. For example, in the art of radioactive assay well logging an assay tool is lowered into the well to the level of a formation to be assayed. The assay operation is then carried out by cyclically operating a neutron source in the tool in order to irradiate the formation under investigation with repetitive bursts of fast neutrons. In one assay procedure, disclosed in U.S. 3,686,503, delayed fission neutrons emitted by uranium within the formation may be detected by a neutron detector. Another procedure, disclosed in U.S. Pat. 4,180,730, involves detection of prompt fission neutrons emitted from uranium in the formation. Pulsed neutron logging techniques may also be employed in procedures in which radioactive decay rates are determined. In this case, the

formation under investigation is irradiated with a burst of fast neutrons and the resulting neutron population is detected during successive or overlapping time windows. For example, U.S. 3,800,150 discloses a pulsed neutron logging technique in which epithermal neutron decay or thermal neutron decay is measured by employing time windows for detection which partially overlap one another.

Neutron sources for use in the radioactive logging procedures as described above may take the form of accelerator-type neutron tubes comprising a target section, a replenisher section, and an ionization section located between the target and the replenisher section. The replenisher section provides a source of accelerator gas to the ionization section where it is ionized and then accelerated to impact the target. The target is formulated of material which responds to the bombarding ions to produce neutrons. In a number of well known accelerator-type tube sources, heavy isotopes of hydrogen are employed as the accelerator gas and in the target. For example, the accelerator gas may take the form of deuterium or mixtures of deuterium and tritium and the target may include tritium molecules, deuterium molecules or mixtures of deuterium and tritium molecules. The so-called deuterium-tritium nuclear reaction is one commonly employed in an accelerator-type neutron tube to produce neutrons. In the replenisher section a filament or reservoir usually made of zirconium or titanium is electrically heated under controlled conditions to release deuterium gas previously adsorbed in the filament or reservoir. Zirconium and titanium have the property of adsorbing large quantities of different gases such as hydrogen, deuterium, tritium, and other gases. These materials have the further property of releasing the hydrogen isotope gases in a controlled manner when heated to about 300°C. and at the same time retaining other gases that may have been adsorbed. The deuterium molecules are ionized in the ionizing section by the application of a positive voltage to an anode in the ionizing section. The deuterium ions are then accelerated and impact the tritium target to produce a supply of neutrons.

While various techniques may be employed in ionizing the accelerator gas, one ionization technique which is suitable particularly where the neutron source is operated at a low accelerator gas pressure and in a pulsed mode is the so-called Penning method. A Penning ion source comprises spaced cathodes and an anode located intermediate the cathodes. In a cold-cathode type Penning ion source, electrons are emitted from a cathode surface by field emissions when a positive voltage pulse is applied to the anode. A magnet associated with the source functions to spiral the electrons thus increasing their flight path and increasing the statistical probability that they will collide with molecules of accelerator gas supplied to the ionization chamber. In a well designed Penning ion source, some of the electrons originating at one cathode surface will impact the other cathode surface and secondary electrons are emitted which also function to increase the ionization reactions. Such ion sources are well known in the art and are described in Flinta, J. "Pulsed High-Intensity Ion Source", Part I; Pauli, R. and Flinta, J. "Pulsed High-Intensity Ion Source", Part II, Nuclear Instruments 2, pp 219-236 (1958). In a hot-cathode type Penning ion source, one cathode is a heated filament and initial electrons are supplied by thermionic emission from the filament. In all other respects, cold-cathode and hot-cathode Penning ion sources are essentially the same. Hot-cathode ion sources are also well known in the art and one such source is described in Wood, J. and Crocker, A. "An Electrostatically Focused Ion Source And Its Use In A Sealed-Off D.C. Neutron Source", Nuclear Instruments And Methods 21, pp 47-48 (1963).

In accordance with one aspect of the present invention, there is provided a method for controlling the operation of an accelerator-type neutron source having a target, an ionization section, and a replenisher for supplying accelerator gas which is ionized upon application of a positive voltage to the ionization

section and accelerated toward the target for the production of neutrons, comprising the steps of:

- a) producing a positive voltage pulse during a desired time period for each burst of neutrons from said neutron source,
- b) applying said positive voltage pulse to said ionization section to produce a burst of neutrons during said desired time period,
- c) producing a negative voltage pulse upon the termination of said positive voltage pulse, and
- d) applying said negative voltage pulse to said ionization section to effect a sharp cut-off to said burst of neutrons.

In a further aspect, the invention resides in a pulsed neutron source comprising

- a) an accelerator tube having a target, an ionization section, and a replenisher for supplying accelerator gas which is ionized and accelerated toward the target for the production of pulses of neutrons,
- b) means for producing clock pulses at the desired repetition rate for said pulses of neutrons,
- c) means for producing a first gating signal having a time period equal to the desired time period for each pulse of neutrons,
- d) means for producing a second gating signal in response to the termination of said first gating signal,
- e) pulse forming means for producing a positive voltage pulse in response to said first gating pulse and a negative voltage pulse in response to said second gating signal, and
- g) means for applying said positive and negative voltage pulses to said ionization section, whereby said positive voltage pulse provides for the ionization of said accelerator gas and the resulting production of neutrons during the time period of said positive voltage pulse and said negative voltage pulse provides for a sharp cut-off to said ionization and the resulting production of neutrons.

In the accompanying drawings, FIG. 1 is a schematic illustration of a radioactive well logging system employing an accelerator-type neutron tube,

FIGS. 2 and 4 are electrical schematics of a circuit for controlling the accelerator-type neutron tube of FIG. 1 in accordance with one example of the invention, and

FIGS. 3A-3D represent waveforms of signals at various points within the circuit of FIGS. 2 and 4.

Referring to FIG. 1, the system comprises a logging tool 3 which is suspended from a cable 4 within a well 5 traversing a subterranean formation of interest indicated by reference numeral 6. The well bore may be lined or unlined with a casing but will normally be filled with a fluid such as drilling mud, oil or water. Signals from the logging tool are transmitted uphole via suitable conductors in the cable 4 to an uphole analysis and control circuit 8. Circuit 8 operates on the downhole measurements and applies one or more output functions to a recorder 9. In addition, circuit 8 transmits certain control functions to the logging tool via conductors in cable 4. As the logging tool is moved through the hole, a depth recording means, such as measuring sheave 10, produces a depth signal which is applied to recorder 9, thus correlating the downhole measurements with the depths at which they are taken.

The logging tool 3 comprises a pulsed neutron source 12, a downhole power supply 14 for the source, and a radiation detector 15, which responds to primary or secondary radiation in the formation in response to the output of the pulsed neutron source. For example, the detector 15 may be a gamma ray detector, a thermal neutron detector or an epithermal neutron detector. While only one detector is shown, it will be recognized that such logging tools may comprise a plurality of detectors responsive to similar or dissimilar radiation.

The pulsed neutron source is an accelerator-type neutron tube comprising a replenisher section 16, an ionization section 18, and a target section 19. Replenisher section 16 may comprise replenisher element 16a which releases deuterium gas in response to

an applied DC or AC voltage from power supply 14. Target section 19 comprises a tritium target 19a. The target section will also typically include an extraction-focusing electrode assembly and a negative high voltage supply (not shown) which functions to direct ions from the ionization section 18 towards the target 19a while suppressing the counter current flow of secondary electrons produced by ion impact on the target. The ionization section 18 includes anode means 18a and cathode means 18b and 18c.

The neutron source 12 may be operated in a continuous or in a pulsed mode. In either mode of operation, deuterium gas released upon the application of power to the replenisher element 16 enters the ionization section 18 where the gas molecules are ionized by a positive (with respect to cathodes 18b and 18c) ionization voltage applied across anode 18 and cathodes 18b and 18c. The deuterium ions formed in the ionization section are then accelerated toward the target 19a by a negative voltage applied to the target section. For example, a positive voltage or voltage pulse with an amplitude from a few hundred volts to a few kilovolts may be applied to anode member 18a and a - 100 kilovolt voltage applied to target section 19.

Referring now to FIGS. 2 to 4 there is shown a circuit for triggering the ionization section of the accelerator-type neutron tube to produce neutron bursts of short duration and sharp cut-off. More particularly, the circuit includes a time base generator 50 which produces clock pulses at a desired repetition rate as shown in FIG. 3A. This repetition rate is the desired firing rate for the pulsed neutron source. Each such clock pulse fires the trigger generator 51, preferably a one-shot multivibrator to provide a trigger pulse as shown in FIG. 3B. A positive pulse discharge unit 52 is activated during the time period of trigger generator 51 to discharge a first portion 53a of the pulse forming network 53. This produces discharge current 54a in the direction shown in the top half 54c of the center-tapped transformer 54 as shown in FIG. 2. As a result of this discharge, a positive going pulse is produced in the secondary 54e of the transformer 54 as shown in the positive position of the waveform of FIG. 3D.

Upon termination of the trigger pulse of FIG. 3B from trigger generator 51, a delay trigger generator 55 is fired. Trigger generator 55 also preferably includes a one-shot multivibrator for providing a delay trigger pulse as shown in FIG. 3C. A negative pulse discharge unit 56 is activated during the time period of delay trigger generator 55 to discharge a second portion 53b of the pulse forming network 53. This produces discharge current 54b in the direction shown in the bottom half 54d of the center-tapped transformer 54 as shown in FIG. 2. As a result of this discharge, a negative going pulse is produced in the secondary 54e of the transformer 54 as shown in the negative portion of the waveform of FIG. 3D.

The secondary 54e of transformer 54 is connected directly to the ionization section 18 of the neutron source 12. The voltage provided within the secondary 54e of transformer 54, as represented by the positive and negative going pulses of FIG. 3D, is applied as the ionization voltage to the anode 18a of the neutron source 12. The deuterium gas molecules released by the replenisher 16 enter the ionization section 18 and are ionized by the positive going portion of the ionization voltage applied to the anode 18a. These deuterium ions are then accelerated toward the target 19 where, upon impact, they produce the desired burst of neutrons so long as a positive ionization voltage is applied to anode 18a.

In accordance with the foregoing description, the present invention provides for a sharp cut-off for each burst of neutrons from the pulsed neutron source through the reversal of the polarity of the ionization voltage to a negative value at the end of the desired burst period. This feature is accomplished by employing the pulse forming network of FIG. 2 as described above to produce the ionization voltage waveform as shown in FIG. 3D. The positive going portion of the waveform is utilized to ionize the deuterium ions while the negative going portion provides the desired sharpness for the cut off of such ionization.

Referring now in particular to FIG. 4 there is shown a discharge unit 60 suitable for use as the positive and negative

pulse discharge units 52 and 56. The operation of discharge unit 60 will now be described in conjunction with its use as the positive pulse discharge unit 52. During the time period of the trigger pulse, FIG. 3B, from trigger generator 51, a driver 61 provides current flow through resistor 62 for gating switching means 59. The switching means 59 comprises a field effect transistor 63 connected in series with the emitter of a transistor 64 which is base-biased by zener diode 65 from voltage supply $+V_A$ along with capacitor 66, resistor 67 and diode 68. The collector of transistor 64 is connected through a transformer 69 to the pulse forming network 53a of FIG. 2. Capacitors 70 of pulse forming network 53a are charged to the supply voltage $+V_B$ through inductance 71, diodes 72, 73 and 74, inductances 75 and the top portion 54c of the center-tapped transformer 54. When the field effect transistor 63 of discharge unit 60 is gated on the charge stored on the capacitors 70 of pulse forming network 53a is discharged to ground through transformer 69, transistor 64 and field effect transistor 63a. This creates current flow 54a in the top portion 54c of the center-tapped transformer 54. The resulting voltage created in the secondary 54e of transformer 54 is a positive voltage pulse of about 2 to 3 kilovolts as shown in the positive going portion of the waveform of FIG. 3D. Following the termination of the trigger pulse from trigger generator 51 to driver 61 of the discharge unit, the bank of capacitors 70 of pulse forming network 53a charges toward the supply voltage $+V_B$.

In similar operation, the discharge unit as shown in FIG. 4 is utilized as the negative pulse discharge unit 56 to discharge the pulse forming network 53b during the time period of the delay trigger generator as shown in FIG. 3C. During this time period current flow 54b is created in the bottom portion 54d of the center-tapped transformer 54 to induce a negative voltage pulse of about 2 to 3 kilovolts in the secondary 54e of transformer 54 as shown in the negative going portion of the waveform of FIG. 3D.

In one practical embodiment of the circuit shown in FIGS. 2 and 4, a 15 microsecond pulse was produced utilizing the following specific types of circuit components.

<u>Reference Designation</u>	<u>Description</u>
Time base generator 50	CD-4047B (R.C.A.)
Trigger generators 51 and 55	CD-4098BE (R.C.A.)
Driver 61	CD-4098BE (R.C.A.)
Field effect transistor 63a	IRF-131 (Inter Ration Rectifier)
Transistor 64	MJ 12005 (Motorola)
Zener diode 65	30 volt
Resistor 67	56K, 2W
Capacitor 66	0.22 f
Transformer primaries 54c and 54d	50 ohms
Transformer secondary	3.2 K
+V _B	150 to 250 volts
Pulse forming network 53	Model 210 (Geotronics)
Capacitors 70	0.016 μ f
Inductances 75	90 μ h

CLAIMS:

1. A method for controlling the operation of an accelerator-type neutron source having a target, an ionization section, and a replenisher for supplying accelerator gas which is ionized upon application of a positive voltage to the ionization section and accelerated toward the target for the production of neutrons, comprising the steps of:

- a) producing a positive voltage pulse during a desired time period for each burst of neutrons from said neutron source,
- b) applying said positive voltage pulse to said ionization section to produce a burst of neutrons during said desired time period,
- c) producing a negative voltage pulse upon the termination of said positive voltage pulse, and
- d) applying said negative voltage pulse to said ionization section to effect a sharp cut-off to said burst of neutrons.

2. A pulsed neutron source comprising

- a) an accelerator tube having a target, an ionization section, and a replenisher for supplying accelerator gas which is ionized and accelerated toward the target for the production of pulses of neutrons,
- b) means for producing clock pulses at the desired repetition rate for said pulses of neutrons,
- c) means for producing a first gating signal having a time period equal to the desired time period for each pulse of neutrons,
- d) means for producing a second gating signal in response to the termination of said first gating signal,
- e) pulse forming means for producing a positive voltage pulse in response to said first gating pulse and a negative voltage pulse in response to said second gating signal, and
- g) means for applying said positive and negative voltage pulses to said ionization section, whereby said positive voltage pulse provides for the ionization of said accelerator gas and the resulting production of neutrons during the time period of said positive voltage pulse and said negative voltage pulse provides for a sharp cut-off to said ionization and the resulting production of neutron.

3. The pulsed neutron source of claim 2 wherein said pulse forming means comprises:

- a) a transformer center-tapped on its primary side to provide an upper primary portion and a lower primary portion,
- b) a first pulse forming network connected across the upper primary portion of said transformer,
- c) a second pulse forming network connected across the lower primary portion of said transformer,
- d) means for charging said first and second pulse forming networks,
- e) means for discharging said first pulse forming network during the time period of said first gating signal to produce a discharge current flow through the upper primary portion of said transformer, whereby said positive voltage pulse is produced across the secondary of said transformer, and
- f) means for discharging said second pulse forming network during the time period of said second gating signal to produce a discharge current flow through the lower primary portion of said transformer, whereby said negative voltage pulse is produced across the secondary of said transformer.

4. The pulsed neutron source of claim 3 wherein said means for discharging said first pulse forming network comprises:

- a) switching means connected across said first pulse forming network and providing a discharge path for said first pulse forming network when activated, and
- b) means for applying said first gating signal to said switching means, said switching means being activated during the time period of said first gating signal.

5. The pulsed neutron source of claim 4 wherein said switching means includes a field effect transistor having said first gating signal applied to its gate input.

6. The pulsed neutron source of claim 3 wherein said means for discharging said second pulse forming network comprises:

a) switching means connected across said second pulse forming network and providing a discharge path for said second pulse forming network when activated, and

b) means for applying said second gating signal to said switching means, said switching means being activated during the time period of said second gating signal.

7. The pulsed neutron source of claim 6 wherein said switching means includes a field effect transistor having said second gating signal applied to its gate input.

2712H/0159H

FIG. 1

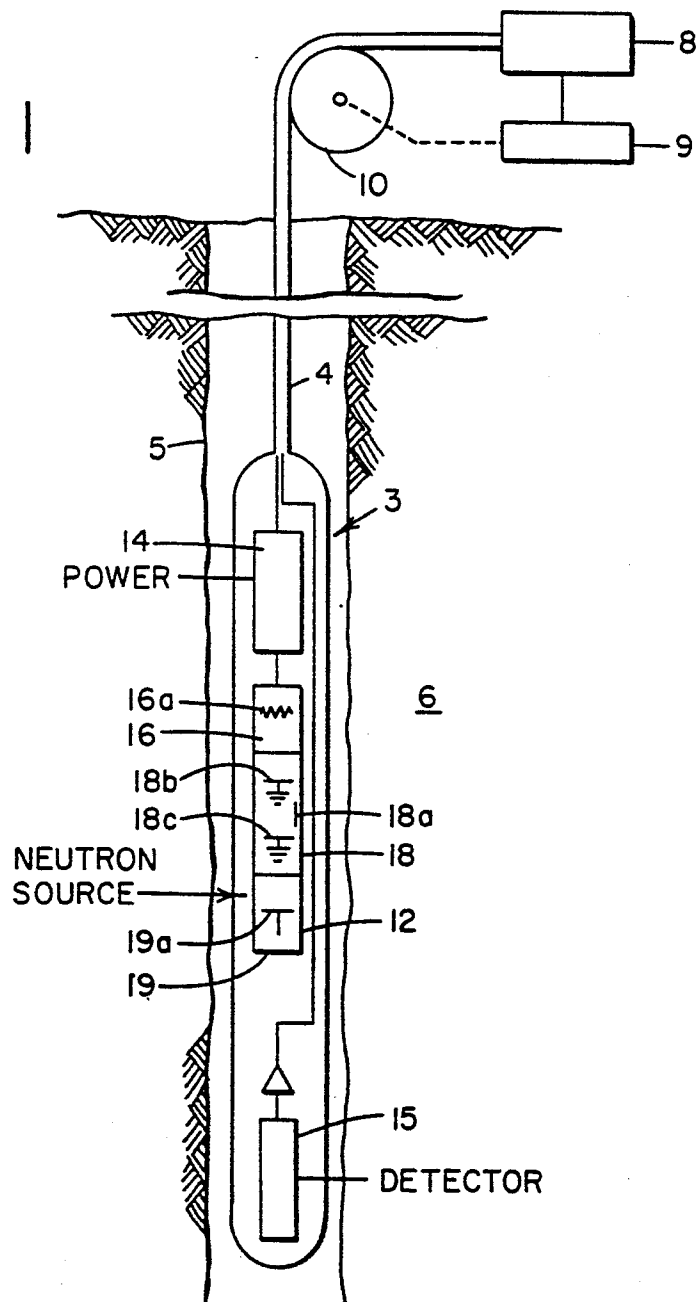


FIG. 3A

FIG. 3B

FIG. 3C

FIG. 3D

