TIME INTERVAL APPROACH TO THE PULSED NEUTRON LOGGING METHOD

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ABSTRACT

The time interval of neibouring neutrons emitted from a steady state neutron source can be treated as that from a time-dependent neutron source. In the rock space, the neutron flux is given by the neutron diffusion equation and is composed of an infinite number of "modes". Each "mode" is composed of two die-away curves. The delay action has been discussed and used to measure the time interval with only one detector in the experiment. Nuclear reactions with the time distribution due to different types of radiations observed in the neutron well-logging methods are presented with a view to getting the rock nuclear parameters from the time interval technique.

Keywords Time interval, Steady state neutron source, Delay action, Neutron logging method

1 INTRODUCTION

The time analysis of the neutrons reacted with rocks when irradiated by a pulsed neutron beam has become an important tool in many well-logging methods applied to oil and mineral geophysics. The method is now applied almost routinely in some countries. The method requires a pulsed borehole neutron generator. Such a neutron source has not only rather high price, but also other disadvantages, *e.g.* limitation in the borehole tool diameter, and difficulty in maintaining a constant neutron output per burst. All these limit some extent of the application of the time dependent neutron method.

It is suggested that the same time dependent information be gotten using the usual isotopic neutron source of the (α, n) or fission type[1]. The biggest advantage of the method is in a simple construction of the downhole tool. The disadvantage, however, is necessarily to design special time correlators working in the real time mode. For the case of the short time channel width Δt, it is rather a troublesome technical task. When the cross-covariance method is applied with the neutron source having a high neutron output, it not only needs a very fast electronics, but also require two detectors. The question is whether it is possible to get the same effect using the usual steady state neutron source, a simple electronics and only one detector in comparison with the method described above. This question will be answered below.

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2 GENERAL OUTLINE

There is a constant average neutron output for a steady state neutron source. m is the average neutron number emitted from the source per second. Thus, the probability of emitting kth neutron can be expressed as distribution with the parameter m[2]

$$P(k) = m^k/k! \cdot e^m \qquad (k = 0, 1, 2, 3, \cdots\cdots) \tag{1}$$

and the time interval t of the close neutron is given by

$$P(t) = m\, e^{-mt} \tag{2}$$

Eq.(2) shows that the probability in a short time interval is more than in a long time interval. Eq.(2) could be chosen as a time-dependent neutron source, if a neutron would be chosen as a start single. The neutron diffusion equation in a time-dependent, mono-noenergetic neutrons filed in a medium can be written[3]:

$$\frac{1}{v}\frac{\partial\phi(r,t)}{\partial t} = D\nabla^2\phi(r,t) - \sum_a \phi(r,t) + s(r)me^{-mt} \tag{3}$$

where ϕ(r, t) is the thermal neutron flux, D the thermal neutron diffusion coefficient, $\sum_a$ the absorption cross section for thermal neutron, v the thermal neutron velocity, $s(r)$ the thermal neutron source intensity at position r.

Green's function $G(r', t', r, t)$ of Eq.(3) which is the solution of the following equation is

$$\frac{1}{v}\frac{\partial G(r',t';r,t)}{\partial t} = D\,\nabla^2 G(r',t';r,t) - \sum_a G(r',t';r,t) + \delta\,(r'-r)\,\delta\,(t'-t) \tag{4}$$

The neutron flux will be

$$\phi\,(r,t) = \int_{r'}\int_{t'} G\,(r',t';r,t)\,s\,(r')\,me^{-mt'}\mathrm{d}^3r'\mathrm{d}t' \tag{5}$$

which is a simple convolution of Green's function with the source density distribution.

It is quite evident that Eq.(4) is a neutron diffusion equation with a pulsed source at time t' and position r'. Assuming that the linear dimensions of the medium are large in comparison to the mean free path, the Green's function is given by

$$G\,(r',t';r,t) = \sum s_n v R_n(r';r)\,e^{-\lambda_n(t-t')} \tag{6}$$

where $R_n(r', r)$ is the eigenfunctions of the following equation:

$$\nabla^2 R_n\,(r';r) + b_n^2\,R_n(r',r) = 0 \tag{7}$$

and b_n is the eigenvalues with the boundary condition $\phi = 0$ on the effective surface of the medium. The s_n is the coefficient in the expansion of the source function in these eigenfunctions. Here,

$$\lambda_n = v\,(\sum_a + D\,b_n^2) \tag{6'}$$

Thus, the neutron flux is given with a neutron source $s(r')me^{-mt}$:

$$\phi(r,t)=\sum\frac{\phi_n(r)}{(m-\lambda_n)}(e^{-\lambda_n t}-e^{-mt}) \tag{8}$$

Here

$$\phi_n(r)=\int_{r'}s_n vmR_n(r';r)s(r')\mathrm{d}^3r' \tag{9}$$

The $\phi_n(r)$ is only position function, not a time one.

The neutron flux is composed of an infinite number of "modes". Each "mode", however, is composed of two die-away with the relaxation time $1/\lambda_n$ and $1/m$. But, there is only one relaxation time $1/\lambda_n$ in a "mode" for the pulsed source[3].

The neutron source becomes time-dependent because of a steady state neutron chosen and determining time interval. The resulted neutron flux becomes difference in comparison with the pulsed neutron source. The following two cases are discussed now.

Firstly, $m \gg \lambda_n$. The steady state neutron source intensity has a high neutron output. The term of e^{-mt} decays very fast with increasing t. For very long time the flux prodominates; *i.e.*

$$\phi(r,t)\approx\sum\frac{\phi_n(r)}{m}e^{-\lambda_n t} \tag{10}$$

is similar to pulsed neutron source. The probability of the neutron in Eq.(2) is concentrated on short time interval, because of the high neutron output. Hence, the result is very similar to a pulsed neutron source for long time.

Secondly, $m \ll \lambda_n$. It is a very low neutron output. Because the term of absorption decays very fast, the flux prodominnates, *i.e.*

$$\phi(r,t)\approx\sum\frac{\phi_n(r)}{\lambda_n}e^{-mt} \tag{11}$$

for very long time. It changes to the time interval distribution of the neutron source.

3 GENERAL THEORETICAL APPROACH

We know from Eq.(8) that the neutron flux vanishes everywhere at $t=0$. Thus, for $t>0$, the neutron flux has the extreme. The optimum value of t_n is derived from the following equation,

$$\frac{\partial\phi(r,t)}{\partial t}\Big|_{t=t_n}=0 \qquad (n=0,1,2,3,\cdots\cdots) \tag{12}$$

The observed value t_n is

$$t_n=(m-\lambda_n)^{-1}\ln(m/\lambda_n) \qquad (n=0,1,2,3,\cdots\cdots) \tag{13}$$

When $b_0=0$, Eq.(13) become

$$t_0=\frac{1}{(m-v\sum_a)}\ln(\frac{m}{v\sum_a}) \tag{14}$$

Usually t_n decreases with increasing n. On the other hand. When m is constant. the optimum value of the neutron flux tends to zero point with increasing the absorption cross section $\sum_a$. The maximum of t_n is t_0.

When all parameters are constant, the flux of the nth term is decreasing with increasing n. The optimum value of the nth term is decreasing, too. Thus, the optimum of the neutron flux is mainly contributed by $n = 0$.

We know from Eq.(8) that the longer the time interval t is, the smaller the difference between two neutron fluxes at different absorption cross sections, and that for a long time, the flux of the larger absorption cross section tends to the flux of the smaller. In physics principle, the time interval of the neibouring neutrons becomes longer because of the neutron absorption. On the other hand, the neutron, which is original neibouring neutron, is absorbed and the probability increases for long time.

4 DIRECT APPLYING CONSIDERATIONS

Now let us discuss how the only one detector is applied to receiving the close neutron signals. The scheme of the set-up is shown in Fig.1. The signal from the neutron detector, firstly, is waved in a waver, then divided into two signals. One signal which is delayed pass a timing discriminator (TD) into a time amplitude converter (TAC) as an ending signal. The other pass directly a TD into a TAC as a beginning signal. The result is recorded by a MCA computer. Except that the first neutron detected is lost in all the measuring time, the system can be used to measure time interval of the neibouring neutrons. Because how to select the time zero point have not any effect on die-away curve of Eq.(8), the delay time can be chosen wilfully. A very successful attempt to use this technigue was obtained[4].

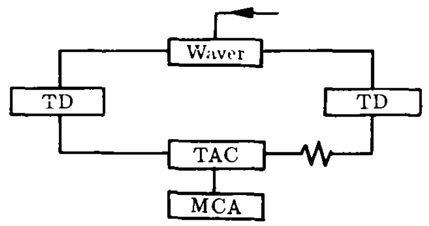

Fig.1 The experimental set-up for the time interval

On the technigue, of all kinds, steady state neutron sources can be used, for example, the usual isotopic neutron sources of the (α, n) or fission types. The intensity of neutron source is not limited.

The neutrons emitted from a neutron source are measured by a neutron detector at a certain distance r from the source. The neutron logging methods with fast neutron source of the steady state is to measure time interval of the neibouring neutrons (The neutron count can be measured at the same time). If a slow and thermal neutron detector was chosen (for example ^{3}He counter), the moderating and absorbing information could be determined.

The other neutron logging methods with fast neutron source, being of some interest for the concept in this paper, are as follows:

a. The first is the time interval of the epithermal neutron. The method can directly give the moderating information. The detector involved with cadmium can measure the epithermal neutron.

b. Two neutron detectors are placed at two certain distances, r_1 and r_2, from source respectively. The two detectors can be also used to measure the crossed time interval of them. In the method, three time interval distributions is measured.

c. When the spectrometric γ-ray detector, shielded against the γ radiation from source, is used instead of a neutron detector, the time interval of the γ-ray (inelastic scattering, radiative capture and activation) can be measured for different γ-ray energy lines and used to analyze carbon, oxygen and other elements.

5 REMARKS AND CONCLUSIONS

It has been shown in present work that pulsed neutron logging is possible without any pulsed neutron source, applying the ordinary steady state neutron source only. The technique which has been used, however, is of the delay action. The distinguished advantage of this method is in a very simple construction of the downhole tool and electronics. The neutron source is not limitted and is only of steady state. The main disadvantage is the difference of die-away curves at various neutron source intensities. On the other hand, the neutron source intensity has an effect on the die-away curve.

In conclusion, one has to be emphasized that the technique of detecting the time interval, described above, is very useful not only in well logging geophysics, but also in other industrial applications when the neutron method is used, and not only in detecting neutrons, but also in measuring γ-rays when the γ-ray method is used. As a matter of fact, the method is almostly used in the nuclear reactor technique, where it is known as the steady state.

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