Research on Analog Signal Source of Gamma Ray Spectrum Logging Technology

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Abstract. Gamma ray spectrum logging tool acquires reservoir information by detecting gamma ray from formation. It has strict requirements for preservation and use, which is not convenient for college teaching. This paper introduces the design of an analog signal source for gamma ray spectrum logging tool, which generates random number based acceptance-rejection method. These random numbers are converted into electronic pulse signal by data acquisition system. It can simulate the electric pulse signal obtained from gamma ray through stratum. The statistical law of energy spectrum from simulation signal source accords with the probability distribution law of pulse signal generated gamma ray from formation. The analog signal source of gamma ray spectrum logging tool can generate simulation gamma ray logging signal without formation model and radiation source, which is of great value for efficient teaching.

1. Introduction

In the process of oil and gas exploration, logging technology is an engineering technology that solves geological problems with the principles of physics. Its measuring principles include electrical logging, acoustic logging and nuclear logging [1][2]. Gamma spectrum logging is an important nuclear logging method. In the borehole, the energy spectrum information of the gamma ray is recorded and analyzed, which evaluates the oil and gas reservoir information of the reservoir and solves the problems in geology and oilfield [3-6]. In the process of logging, gamma ray spectrum logging tool detects the gamma ray from the stratum. Therefore, when teaching gamma ray logging technology in colleges and universities, a realistic stratum model should be built for the calibration of logging tool. Furthermore, the radiation protection level of the laboratory must meet the basic standards of national ionizing radiation protection and radiation source safety, and must have the relevant qualification recognized by the state. It raises the threshold of nuclear logging teaching activities for logging instrument majors in colleges and universities. In order to reduce the threshold of nuclear logging teaching in Colleges and universities, this paper studies the analog signal source technology of gamma energy spectrum logging, analyzes the energy spectrum of scattering gamma ray from the formation, discusses the algorithm of generating signal pulse in accordance with the energy spectrum distribution, and puts forward the working program of analog signal source, which simulates the photoelectric pulse signal generated by gamma ray.

2. Generation principle of gamma ray energy spectrum

Gamma spectrum logging analyzes the spontaneous or scattered gamma spectrum distribution information from the formation to estimate the formation information [7-9]. Fig. 1 is the gamma ray energy spectrum curve generated by the stratum. The horizontal axis is the energy and the vertical axis
is the counting rate of unit energy area. The counting rate of gamma ray is the statistics of the total number of electric pulses received in the unit energy area. In measurement, even if the measurement conditions are unchanged, the counting rate of each measurement is not constant, but the fluctuation around a certain value, that is, the statistical fluctuation. The counting rate changes with the change of gamma ray energy, and the change rule of energy spectrum is affected by the lithology, density and other parameters of surrounding strata.

![Figure 1. gamma ray energy spectrum curve of strata](image)

According to the design purpose, the simulation signal source of gamma ray energy spectrum logging generates electronic pulse signal, whose pulse amplitude is directly proportional to the energy of gamma ray pulse signal, and the magnitude is random. The probability density distribution of pulse amplitude statistics should be consistent with the energy spectrum curve law shown in Figure 1.

### 3. Algorithm of random signal generation

In the design of analog signal source of gamma spectrum logging, it is necessary to generate random number with specific distribution. The main methods of generating random numbers according to the specified probability distribution are inverse function method, transformation method and acceptance-rejection method.

#### 3.1. Inverse function method

The inverse function method is one of the methods to generate random numbers with specific distribution. Its theoretical principle is: Let the random number y obey the uniform distribution on the [0,1] interval, the random number function of the specific probability distribution is f (x), the inverse function of F (x) is F-1, let x = F-1 (y), then x is the random number obeying the probability distribution function f (x). Therefore, as long as we obtain the inverse function of the specific probability distribution function, we can generate the random number which obeys the specific distribution from the [0,1] uniformly distributed random number.

#### 3.2. Transformation method

A random number of the specific distribution can be transformed into a random number of different distributions by a transformation. For example, linear transformation can transform the distribution on
a finite interval \([a, b]\) to any real number interval \([c, d]\). For each \(x\), \(y\) can be given according to formula (1):

\[
y = \frac{x(c-d)}{(b-a)} + c
\]  

(1)

And the box-Muller transformation can transform two random variables uniformly distributed on the interval \([0, 1]\) into two random variables with normal distribution.

3.3. Acceptance-rejection method

The acceptance-rejection method applied in this paper was first proposed by Von Norman. Its basic idea is: Assuming that the probability density distribution function is \(f(x)\). The random number sequence \(\{r_1, r_2, r_3, r_4\}\) is processed with acceptance-rejection method. The rule to acceptance-rejection is: when the density function \(f(x)\) is large, more random numbers \(r_i\) are reserved; when the density function \(f(x)\) is small, less random numbers \(r_i\) are reserved, so the distribution law of \(r_i\) in the sub-samples will meet the requirements of probability density distribution function \(f(x)\).

The algorithm of acceptance-rejection method is described as follows: [10-11]

1. If the probability density function is \(f(x)\), a uniformly distributed random number \(X \sim \text{Uni}(x_{\text{min}}, x_{\text{max}})\) is generated;
2. Generate another uniformly distributed random number \(Y \sim \text{Uni}(y_{\text{min}}, y_{\text{max}})\) independently;
3. If \(Y \leq f(X)\), return to \(x\), otherwise return to step (1).

Acceptance-rejection method is essentially a simulation method, not a direct mathematical method. Each time a new random number is generated, another random number is used to ensure that the probability of the new random number being accepted obeys the specified probability density function. In the design of analog signal source of gamma spectrum logging, the probability distribution of pulse signal is determined, and the random data of corresponding distribution can be generated by acceptance-rejection method.

4. Program design

The analog signal source of gamma spectrum logging uses data acquisition card to realize the output of signal pulse. The acquisition card program first generates random numbers that obey the uniform distribution, processes the random numbers according to acceptance-rejection method, obtains the new random numbers that obey the same probability distribution as the gamma spectrum logging signals, and converts them into pulse simulation signals and outputs them. The data acquisition card program design flow is shown in Figure 2.
It can be seen from the flow chart that after the acquisition card generates the random data subject to the distribution of gamma spectrum logging signal, it is converted into pulse signal through DA. According to the sampling theorem, in order to distinguish the pulse signal in the subsequent signal receiving circuit, the delay time in each pulse generation cycle is about 4 times of the acquisition time interval.

5. Result analysis
According to the design requirements, the gamma spectrum logging analog signal source is built, which can generate analog pulse signals that meet the requirements of probability distribution. The pulse signals are processed statistically, and the statistical results are shown in Figure 3.
From the statistical results in Fig. 3, it can be seen that the probability distribution of the pulse signal is close to that of the gamma ray energy spectrum curve shown in Fig. 1, indicating that the analog signal source of the gamma ray energy spectrum logging can realize the simulation of the gamma ray pulse signal.

6. Conclusion
The simulated signal source of gamma ray logging discussed in this paper can generate the simulated electronic pulse signal from the gamma ray. The probability distribution of the pulse signal conforms to the parameters of the gamma ray spectrum curve generated by the actual formation. During the use process, there is no need for the actual formation model, no risk of nuclear radiation and the limitation of the use of radioactive equipment, which has practical value in teaching.

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