Electronics Design for Dual Energy Gamma-Ray Multiphase Flow Meter

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Abstract. There are two ways to design nuclear electronics for a dual energy γ ray multiphase flow meter. The advanced way is based on high speed A/D data acquisition and DSP digital signal processing, but it involves a complicated system structure and a huge data flow; the conventional way is based on the technique of photon pulse counter, which is complicated in electrical design, but simple in system structure due to its low data flow. Both systems are studied in the Multiphase Flow Laboratory, Institute of Mechanics, Chinese Academy of Sciences. In this paper, the instrumental designs on the technique of photon pulse counter will be mainly discussed, including the γ ray sensor's characteristics, signals of sensor, preamplifier, filter and shaping amplifier, DC base shift correcting circuit, narrow windows of energy spectroscopy, programmable pulse count acquisition system

Keywords: Dual energy γ ray, Multiphase flow

INTRODUCTION

Oil-water-gas multiphase mixed transportation in oil pipe is extensively used in ocean oil industries. How to measure the flow rate and multiphase volumetric fraction are important in this area of studies. Related research work started since the 1980s. The measurement of component ratios in multiphase flows using γ ray attenuation was first suggested by Abouelwafa and Kendall (1980)[1], and the technique has been used in many current commercial multiphase metering systems. Single energy γ ray technique working as a densimeter is satisfactory in two components measurement of gas/liquid or oil/water pipe-flow if not considering the concentration distribution of the different components in the cross-section. But in oil-water-gas three phase flow, the situation is different. Dual energy γ ray techniques have developed rapidly in the last decade, the different attenuation properties of the three phase's media in the oil pipe are used to deduce the components fraction information. Dual energy γ ray technique has been applied to cases with three basis materials having distribution of linear attenuation coefficients with an obvious variance. It is proved to be a very promising technique for the purpose of simple and fast estimation of the volumetric fraction of oil-water-gas multiphase flow, and it becomes the constituent part of radial base multiphase meter[2].

In this paper, the nuclear instrumental design for a dual energy γ ray system is presented for oil-water-air three-phase pipe flow.

DESIGN PROCEDURES

In the instrumental design of dual energy gamma ray system, the important parameters to be considered are

- selection of detector;
- design of preamplifier;
- design of filter and shaping amplifier;
- design of DC base shift correcting circuit;
- design of dual channels analyzer;
- design of programmable pulse counter data acquisition system.

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Selection of Detectors

The dual energy γ ray technique is based on the measurement of materials' attenuation coefficients with respect to two radioactive isotopes of emission energies 59.5keV and 662keV. An important step in the γ ray system design is the selection of scintillation detectors. Two parameters are important while selecting the scintillation detectors: detection efficiency and decay constant. High detection efficiency is required to reduce the source strength and short decay constant is required for high count rate to avoid pulse pile up or saturation when the system is operated in count mode. NaI (Tl) crystal is the most commonly used scintillator for its highest detection efficiency. Various scintillator properties are tabulated in Table 1.

TABLE 1. The properties of Some inorganic scintillator crystals

Scintillator	Decay constant (us)	Density	Efficiency (%)
NaI (TI)	0.23	3.67	100
CsI (Na)	0.63	4.51	85
CsI (TI)	1.0	4.51	45
CsF	0.005	4.11	3
LiI (Eu)	1.4	4.08	35
CaF2 (Eu)	0.9	3.19	50
BaF2	0.63	4.88	10
KI (TI)	0.24/0.25	3.13	24
Ps	0.002	1.05	5

The function of the detector is to produce a signal for every particle it has recieved. Every detector works on the interaction of particle with matter. A scintillation detector consists of a scintillator and a photo multiplier tube (PMT). Scintillators may be materials of solids, liquids, gases, which produce spark or scintillate light when the ionizing radiation passes through them. The light produced in the scintillator is weak and hence must be amplified before being output as a pulse. A photomultiplier tube is used for multiplication of the light emitted by scintillator. Inorganic and organic scintillators are commonly used for scintillator detectors. Inorganic scintillators, however, are found to be superior to organic scintillators with respective response times of 10 ns and 1 ms. Inorganic scintillators respond much more quickly. NaI (Tl) is the most commonly used inorganic scintillator for gamma rays. It has relatively high density and high atomic number, which makes it an extremely efficient gamma detector. Its light conversion efficiency is the highest of all the inorganic scintillators (100%).

The photo multiplier tube or photo tube is an integral part of a scintillation counter. Without the amplification produced by the PMT, a scintillator is not useful for radiation detection. A PMT is essentially a fast multiplier that amplifies an incident pulse of visible light by a factor of 1000,000 or more in 1 ns.

A photo-tube consists of an evacuated glass tube with photocathode at its center and several dynodes in the interior (Fig. 1).

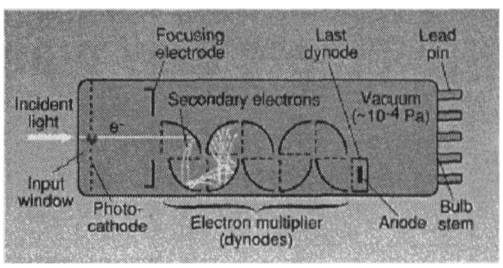

FIGURE 1. Schematic of a photomultiplier tube

The photons produced in the scintillator enter the photo tube and hit the photo cathode, which is made of a material of Cs–Sb compound (used as photocathode in most of the scintillation detectors because its surface has maximum sensitivity for electron emission)and emits electrons when light strikes it. The electrons emitted by the photocathode are guided by an electric field towards the first dynode, which is coated with a substance that emits secondary electrons, if an electron strikes it. The secondary emission rate depends on the applied voltage and on the type of surface. The secondary electrons from the first dynode move towards the second dynode, from there towards the third dynode and so on. The acceleration of electrons from one dynode to another is achieved by applying a successively increasing positive high voltage to each dynode. The voltage difference between two successive dynodes is of the order of 80–120V. Typical commercial photo tubes may have up to 15 dynodes.

The Amplifier

The main purpose of the amplifier is to amplify the signal which comes out of the detector. The signals from the detector are very weak, in mV range. Before it can be recorded, it should be amplified by a factor of thousand or more which is done by the amplifier. In short, the amplifier increases the amplitude of pulse from detectors to a few volts as required by the analyzer that follows the amplifier with the provision for a gain selection and pulse shaping time constant.

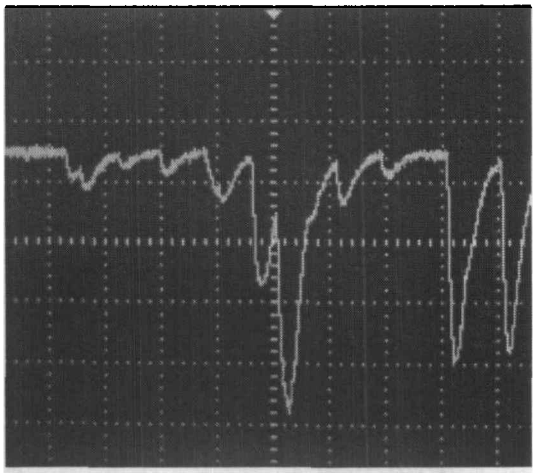

FIGURE 2. The pulse wave form

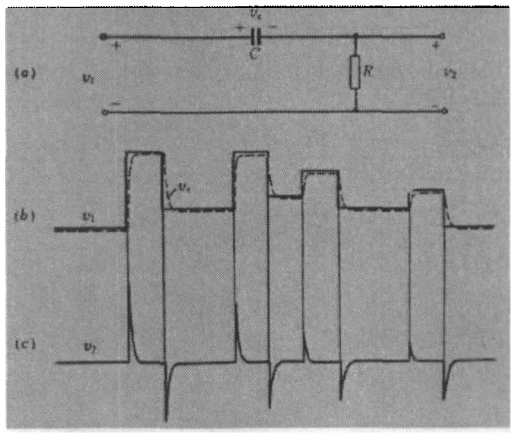

FIGURE 3. RC differential circuit

The pulse signal from amplifier is a series of negative pulses with a significant positive DC base shift, where the amplitude of pulses corresponds to the entered photon energy. The pulse wave form is shown in Fig.2.

DC Base Shift Correcting Circuit

As shown in Fig.3, the positive DC base shift ranges from 1 to 2 volts and takes an indefinite value, perhaps caused by pulse trail pile up, where the shift rate is proportional to the total pulse count rate, a high pulse count rate will cause higher shift voltage at the out of amplifier. In the dual energy gamma ray system, because of the high accuracy requirement of spectrum resolution, the DC base shift is thereby very harmful for pulse measurement, thence a DC base restoring circuit is needed to avoid the DC base shift.

In general, a differential circuit is used as DC isolation. A most common differential circuit is RC circuit, as shown in Fig.3. The circuit time constant RC is chosen to be much shorter than the signal pulse interval. The voltage of capacitance drops to the input signal base rapidly, then the DC base can be restored. Because the time constant RC is much shorter than the pulse assert time, the output pulse of RC circuit becomes narrow and sharp, Fig.3(c), which will make the later spectrum analyzer difficult. An improved CD circuit is proposed as in Fig.4(a). In the CD circuit, a nonlinear component of diode replaces the resistance in RC circuit, its working principle and working wave are shown in Fig.4. The positive resistance of diode is large when it is not leaded, which will produce a larger shift rate than RC circuit, Fig.4(c). In order to solve this problem, an operation amplifier is employed to reduce the inner resistance of the diode,Fig.4(d).

Filter and Shaping Amplifier

The main purpose of the filter and shaping amplifier is to improve the signal to noise ratio and to shape the pulse into a Gauss-like curve. Anything that the filter and shaping does here is actually the same thing in the frequency analysis that they are filtered some frequencies out from the signal. A pole-zero cancellation technique is used. The schematic is shown in Fig.5.

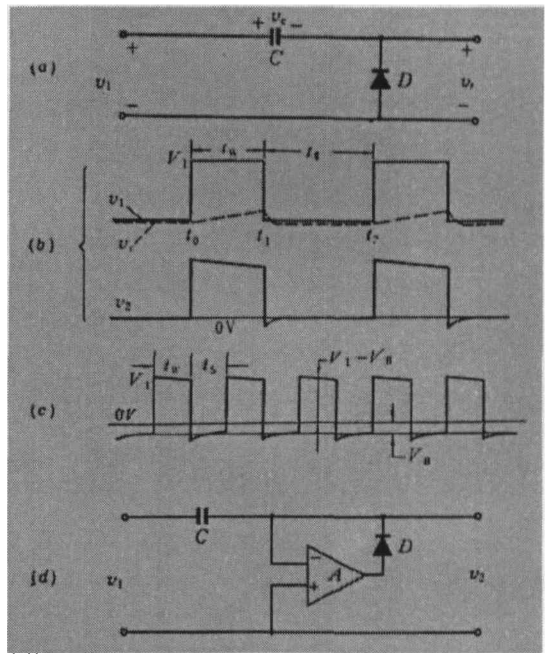

FIGURE 4. CD differential circuit

The output pulses from the shaping amplifier are inverted to positive pulses and the amplitudes are amplified to 0~8V. The pulses are shaped to a Gauss-like curve and are adjusted to only 1~2us wide to avoid pulse pile up for the case of high counts. (Fig.6.)

The pulse amplitude which ranges from 0 to 8V denotes the distribution of the energy spectroscopy as shown in Fig.6.

Dual Channels Analyzer

This is an important unit in the gamma ray spectrometer and does the job of amplitude selection (and hence energy selection) for output pulses from the amplifier. Analyzers have two narrow windows with window selection or lower limit and upper limit level selections. When the pulse goes out of the shaping amplifier, the lower and upper level selections operate, only the photons with energy above the lower threshold energy and below the upper threshold can be counted, thereby rejecting the unwanted low/high energy pulses. The present dual energy system is composed of two radioactive isotopes with emission energies of 59.5keV and 662keV. The dual energy spectroscopy is show in Fig.8.

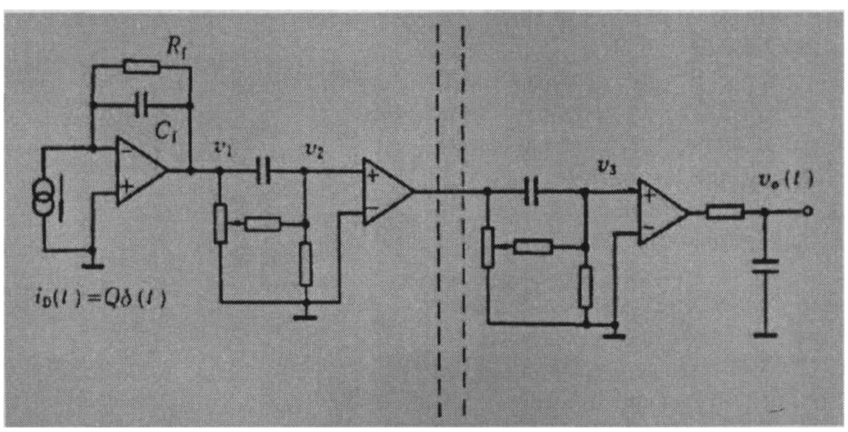

FIGURE 5. A pole-zero cancellation filter and shaping amplifier

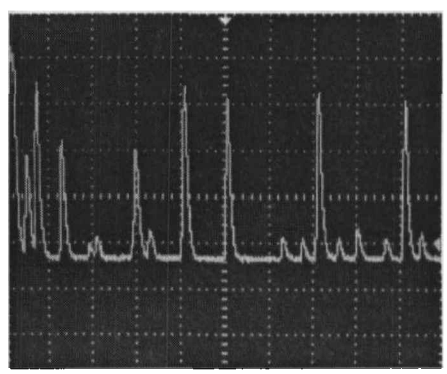

FIGURE 6. Pulses after shaping

With the doses of 100 mCi and 20 mCi, the peak of ^{241}Am is higher than that of ^{137}Cs, and the voltage is narrower , which means that the sensor of scintillator has higher energy resolution and is more efficient for ^{241}Am.

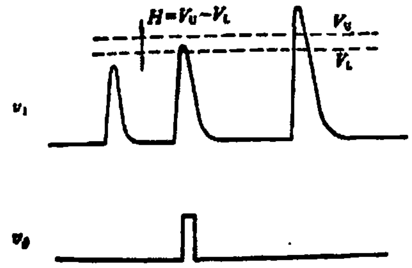

FIGURE 7. Principle of limits

The principle of the two window limits is shown in Fig.7. Only the pulse with amplitude between the low threshold and up threshold can get through, lower or upper pulses will be rejected. The limit circuit comprised of two high speed voltage comparators and associated logic circuits, two adjustable reference window voltages are provided.

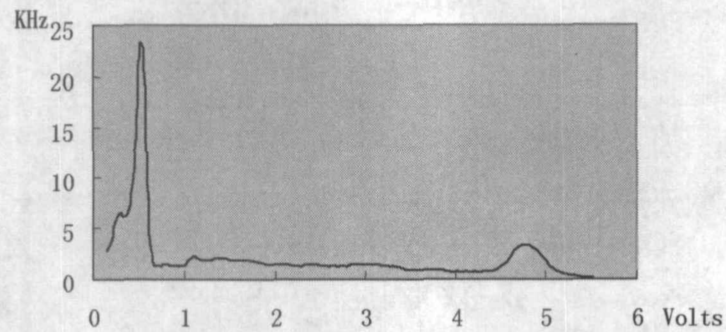

FIGURE 8. Am and Cs dual energy spectroscopy

Data Acquisition System

The data acquisition system is a programmable pulse counter system. Using an Intel Pentium industrial computer, it is equipped with eight boards of 32 channel 16 bit pulse counter in its ISA bus. Total 256 channels of counter are available for the data acquisition system. The counter latch time and counter bit length are programmable; the integral time for every channel is programmable as well. The programmable counter board is based on the chip of 8253, which have three channels of programmable interval timer/counter. It is a commonly used chip in this field, cheap and stable. In order to avoid the pulse deformation (only 100~200ns), digital logic isolation is necessary for the transmission from shaping amplifier to the counting board. An ultra high speed (10MBd) photo coupler 6N137 is employed in the board, therefore, noise and disturbance are eliminated.

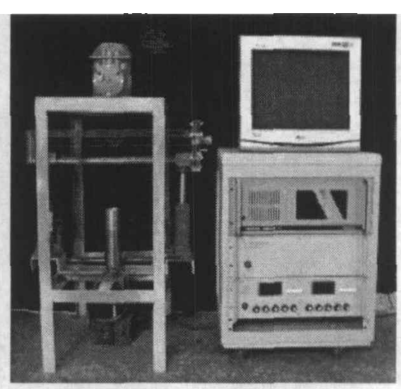

FIGURE 9. Data acquisition system

Another important part in the data acquisition system is the software that enables users to select above control parameters, acquire the data and makes further calculations.

This is a conventional way of data acquisition based on the technique of photons pulse counter, corresponding to the multi-CPU data acquisition system. It has a simple structure and a low data flow rate from instruments to computer.

TEST CURVES

Some experiments were carried out on multiphase flow loop in IOM. The test curves on oil-water-gas three phase flow were obtained. A test curve of slug flow is shown in Fig 10. The dispersed area is bubble, and the continuous area is liquid phase. The left diagram is the signal of ^{241}Am; the right diagram comes from ^{137}Cs channel.

When the bubble passes through the test section, the material attenuation is reduced; then the count rate rises, when the liquid fills the whole test section of the pipe, the material attenuation reaches its maximum, then the count rate drops down. In the ^{137}Cs channel, the signal characteristic is the same as ^{241}Am channel but its total attenuation is less, because of higher emission energy.

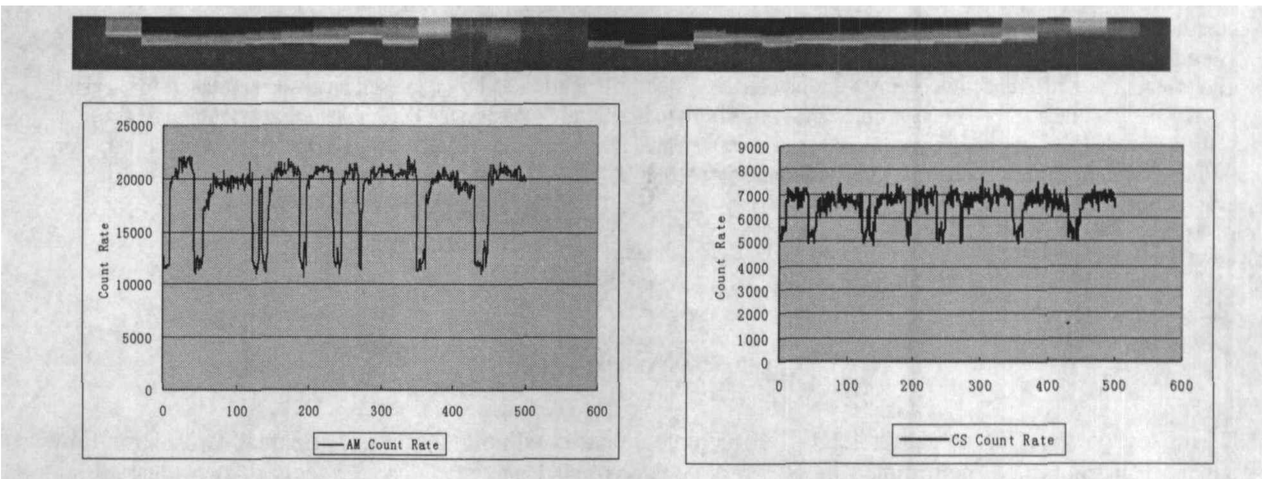

FIGURE 10. Attenuation curve

CONCLUSIONS

In case of a pulse-type dual energy gamma ray system, the output consists of voltage pulses; one pulse per particle is detected. It consists of instruments including scintillator detector, associated amplifiers, dual channel analyzer and data acquisition system.

There are several key points in the nuclear instrumental designs, including DC base shifting and pulse shaping. An appropriate treatment of above questions will increase the accuracy of the dual energy gamma system.

In general, the pulse-type design is a conventional way based on the technique of photons pulse counter; it is simple in system structure and has low data flow

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