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Research and Design of Nuclear Instrumentation Measurement Precision

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Abstract

There are many factors to influence measurement precision of nuclear instrumentation, which include radioactive statistical fluctuation, signal processing method, use environment and so on. Aiming at these factors, this article adopts some concrete methods to enhance measurement precision and makes the isotope level meter (instrumentation) achieve better effects through the designs of hardware and software.

Keywords: Isotope level meter, Measurement precision

With the development of science and technology, the application of nuclear technology in industrial production becomes more and more extensive. Because the nuclear instrumentation has the advantages of non-contact, veracity, delicacy and adopting various complex environments, so its application becomes universal in many industries such as chemical industry, smelting, power generation, cement, paper making and so on, especially in the industries of chemical industry and cement (Xie, 2006). But because of its self characters of isotope instrumentation, it is difficult to achieve higher measurement precision in the actual application, and the general precision is smaller than ±8%, the better is smaller than ±5%, so the measurement precision is difficult to fulfill the requirement under the condition of higher requirement (Gao, 2005). In the research process of intelligent continual level meter (GD-1), through the analysis of influencing factors of measurement precision we adopt some hardware measures and software methods, markedly enhance the measurement precision of isotope instrumentation and obtain satisfactory measurement results.

1. Factors influencing measurement precision

1.1 Statistical fluctuation of radioactive sources

The radiation of radioactive isotope in nature possesses statistical character, i.e. radials radiated in unit time are not complete same, but their averages in long period are equivalent. As to detector, when the liquid level is relative stable, the number of radial detected in every unit time must fluctuate in certain range and is not a changeless constant value. Further speaking, the liquid level calculated by instrumentation is not a constant value too, and it must fluctuate in certain range. In addition, when the liquid level has feeble changes such as 3%, are the changes of liquid level calculated by instrumentation still in the statistical fluctuation of radioactive source? The settlement of these problems directly influences the measurement precision of the entire instrumentation.

1.2 Measurement method and signal processing method

When the radials radiated by radioactive source penetrate substance, part radials will be absorbed by substance, and a sort of logarithm relation not a sort of line relation exists between the radial intensity penetrated and the thickness (or highness), so it is very important for the veracity of measurement to utilize what kind of method to deal with this relation. In the analog circuit, the best method is to adopt two-stage, three-stage or multi-stage pump circuit to describe (or simulate) this relation by phase, and obtain an approximate line relation, so we can get the measurement precision. If we adopt digital circuit, a problem of dealing with logarithm relation still exists, and there is not the digital circuit (or digital circuit combination) which can adopt this requirement. Therefore, it is feasible method to use SCM to realize this function through software programme.

Furthermore, the selection of radial detector component also has important influences to measurement precision.

1.3 Interventions of environment

When the instrumentation is used in the industrial production environment, it must fall under the interventions from environment. The factors such as electromagnetic field, in-phase power supply crest, strength of radioactive natural background produced by high-power apparatus all influence the measurement precision of instrumentation.

2. Hardware design

2.1 Selection of core components

Considering factors of running speed, calculation ability and function extension, the master computer adopts SCM AT89C4051 with interior rapid programmable and erasure memorizer, and extents E2PROM, D/A converter, remote data transmitter and display drive by means of serial expansion technology (He, 2000). Therefore, the entire system can possess characters such as simple circuit structure, rapid running speed, powerful calculation ability and clear information flow, and is fitter to enhance measurement precision by means of software. Figure 1 is the hardware structure schematic diagram of the master computer.

2.2 Detector and radioactive source

Nal (Ti) crystal has higher detecting efficiency, and its energy resolution can achieve above 8.3%. It is the perfect radial detecting receiving device (Gao, 2005).

The radiation detector is composed of Nal (Ti) crystal, multiplier phototube, preamplifier circuit and shaping circuit. The preamplifier circuit is a simple emitter-follower, and the shaping circuit is the monostable circuit composed by 555. The final output is square signals which are sent to the master computer through cable line. Thus the silo signals can be effectively and completely sent to the master computer, and the remote signal attenuation can be reduced.

In addition, it is helpful for the enhancement of measurement precision to properly increase the intensity of the radioactive source.

2.3 Anti-jamming design of hardware

(1) Adopting the module of switch power supply.

(2) Insisting on the cabling principle of minimized power supply loop area.

(3) Photoelectric isolation of in-out and isolation of digital circuit and analog circuit.

(4) Exerting "Watchdog" circuit.

(5) I^2C total line cabling must be as short as possible.

(6) Adopting cable lines to shield.

3. Software design

The core of SCM instrumentation rests with the design of software. For intelligent isotope level meter, it is the core and key of instrument measurement precision design to select proper mathematical model, software design and better anti-intervention measures to effectively eliminate influences of statistical fluctuation. Again, the self-regulation of system running parameters and high precision of calculated results also has certain assuring functions to enhance measurement precision.

3.1 Establishment of mathematic model

When the radials radiated by radioactive source penetrate silo substance, a sort of logarithm relation exists between the radial count number and the silo height, i.e. $P=P_0e^{-\mu_m \rho d}$.

Where, P represents the count rate after medium penetrated, P_0 represents the count rate before medium penetrated, i.e. when d=0, ρ represents the density of medium, μ_m represents the absorption coefficient of quality, and d represents the depth that the radial penetrates the medium.

Supposed that the liquid level is the relative zero position d_0 when the count is N_0, and the liquid level is the full position d_1 when the count is N_1, so when the count is N, the proportional height h of liquid level relative to zero position and full position is $h=d \div d_1 \times 100\% = \ln(N_0 \div N) \div \ln(N_0 \div N_1) \times 100\%$.

To ensure the measurement precision and the error reduction, according the character of logarithm calculation, the above formula can be transformed to $h=\log_2 (N_0 \div N) \div \log_2 (N_0 \div N_1) \times 100\%$.

3.2 "Elimination" of statistical fluctuation influence

Though the statistical fluctuation can not be eliminated, but it has certain rules, so under the permissive conditions of measurement precision, the influences of statistical fluctuation to measurement precision can be weakened through measures such as comparison elimination and continual glide average (Wang, 2003, p.43-44).

3.2.1 Comparison elimination

Supposed that the radial count received by detector in unit time is N_0, when the liquid level is at certain height and relative stable, according to statistical distribution rule we can get the possibility that the count N_1 in the next unit time fall into zone [N_0-σ, N_0+σ] is 68%, and in order to effectively eliminate the measurement error aroused because of statistical fluctuation and timely detect the change of liquid level, two flag positions including flag 1 and flag 2 of liquid level change trend are set up in the program. When N_1 is smaller than N_0-σ, clear flag 2, and if flag 1 is set, so that means the liquid level has changes (reducing), or else, set flag 1 and abandon N_1 and the liquid level reveals that the height has no change, and then review the count N_2 in next unit time. If N_2 is bigger than N_0-σ, so the statistical fluctuations of N_1 and N_2 may not be considered. In the same way, when N_1 is bigger than N_0-σ, the judging method is same to the above method.

3.2.2 Continual glide average

To the counts selected after comparison elimination, we can take the average of recent consecutive 5 counts which include the pulse counts N_1, N_2, N_3 and N_4 in the former 4 time units and the pulse count N in the present time unit as the reference to calculate liquid level in the present unit time, abandon N_4 and hold N, then form new N_1, N_2, N_3 and N_4 for the use of next time. In this way, the influences of same change trend of consecutive two pulse counts aroused by statistical fluctuation to the measurement precision of liquid level can be weakened to a large extent.

Through the comparison of experimental measurement, the two above measures can reduce 4% of measurement error.

3.3 Design of software trap

To prevent the interventions coming from the factors of exterior strong electromagnetic field (wave) and power supply mutation to SCM, we design software traps in the program except for adopting certain methods in the hardware design. When every subprogram is transferred or returned to the main program, the estimation sentence is joined to avoid improper transfer. And the address sentence (0000H) of jumping program is set in the blank position of the program memory to prevent program run away. In the data processing process, the data analysis sentence is joined to eliminate the bigger or smaller data aroused by environment and ensure the availability and rationality of the data (He, 1998).

3.4 Data operation precision

To ensure the veracity and availability of the data, in the program we adopt the format of floating point numbers with multibyte to implement the arithmetic and the logarithm calculation processing to the data, and the significant decimal fraction is three digits. In the program we design the subprogram which can expand 10 and 1/10 times to the data, transform decimal fractions to multibyte integers for calculation, reserve three digit decimal fraction of the calculation result according to round principle, and finally display one digit decimal fraction, consequently the data precision can be guaranteed effectively.

4. Conclusions

The application of above methods can enhance and ensure the measurement precision of instrument to some extent, and the testing and locale applicable results of Henan Provincial Electronic Products Quality Supervision & Inspection Department have shown that the measurement precision of GD-1 γ Level Meter is ≤±2% which is far smaller than the isotope level meters of other types (Wang, 2002, p.561-565). However, as to the enhancement of isotope instrument measurement precision, there are still many methods and measures which can be used (such as the processing technology of yawp), and we welcome your discussions and researches with us together.

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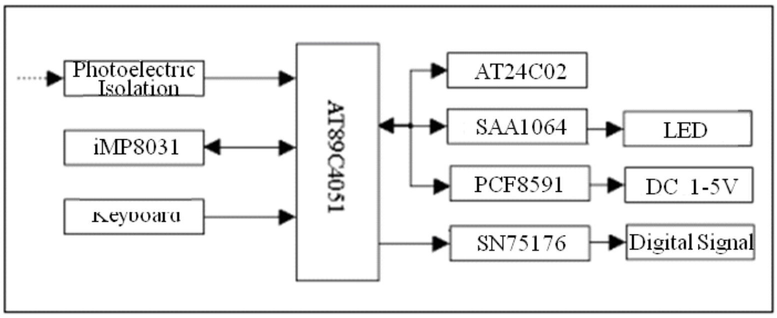

Figure 1. Hardware Structure Schematic Diagram of Master Computer