

Development of neutron moisture gauge in China

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Abstract: According to measuring mode (in-hopper, surface, transmitted and scattered neutron moisture gauge), this paper introduced the development and application of neutron moisture gauge in China since 1970s.

Key words: neutron moisture gauge; neutron detector; neutron source; moisture content; density compensation

1 Introduction

Theory of neutron reaction with hydrogen nucleus is applied to technology of neutron moisture gauge. The neutron moisture gauge has character of keeping measured object clear and nondestructive. The response of the neutron moisture gauge is rapid and sensitive to moisture. The neutron moisture gauge can continually measure moisture content. With the neutron moisture gauge, averaging moisture content can be acquired by integral measurement for some bulk material. When the neutron moisture gauge is a type of non-sampling measurement, it is convenient for automatic production in industry and agriculture. And when the neutron moisture gauge is sampling measurement, it may be used to checking moisture content in laboratory.

There are many kinds of neutron moisture gauges. According to measuring mode, there are in-hopper, surface, transmitted and scattered neutron moisture gauge. According to measuring principle mode, there are slow-down, attenuated and scattered. According to measuring equipment mode, there are immobilizing, portable and sampling.

International, The neutron soil moisture gauge was investigated since 1950s^[1,2]. The neutron gauge was applied to automatic production in industry of steel, architecture and foundry at 1970s. At 1980s, the neutron gauge was applied to measuring moisture content in fertilizer and food. A neutron moisture gauge which is applied in laboratory and to sampling was developed at same time.

In China, the investigation of the neutron moisture gauge had a little working at 1960s. At 1970s, the systemic investigation of the neutron moisture gauge was begun. A neutron moisture gauge of type SHD-1, being a kind of in-hopper neutron moisture gauge, was developed by Nanjing University and gen-

erated by The Eighth Wireless Factory of Wuxi at 1978, as shown in Fig. 1. The first neutron gauge symposium of China was hold at 1983 (Nanjing). In the first meeting, immovable and portable in-hopper neutron moisture gauge was only reported. BF₃ counter was only selected as neutron detector. Only three departments, which are Nanjing University, Lanzhou University and Jiangsu Academy of Agriculture Science, developed this neutron moisture gauge. Only one factory, being The Eighth Wireless Factory of Wuxi, generated neutron moisture gauge. When the second neutron gauge symposium of China was hold at 1987 (Nanjing), investigation and application of the neutron moisture gauge had widely developed in China. Li-glass scintillator and ³He counter etc. had also been selected as neutron detector. Immovable in-hopper neutron moisture gauge have been developed to digital and automatic neutron moisture gauge. Surface neutron moisture gauge was also developed. The neutron moisture gauge with density compensation and sampling was also reported in the second meeting. When the third neutron gauge symposium of China was hold at 1989 (Changsha), many kinds of neutron moisture gauges were reported, for example portable surface and sampling neutron moisture gauge with density compensation, portable in-hopper neutron moisture gauge. Dalian institute of application technology, Peking Nuclear Instrument Factory, Hangzhou Machine Institute and Nanjing Academe of Water Conservancy also reported development of neutron moisture gauge. next several symposium were respectively hold at 1992 (Chengde), 1995 (Shangrao), 1999 (Nanjing), 2003 (Hangzhou) and 2007 (Changchun). In these meeting, neutron moisture gauge was more perfectly developed and more widely applied. Neutron moisture gauge with density compensation and high precision was more reported and put forward to.

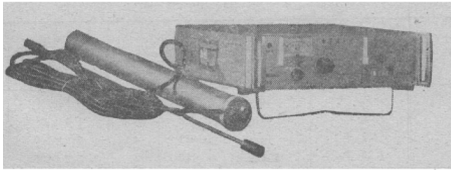


Fig. 1 In-hopper neutron moisture gauge of a type SHD - 1

As the neutron moisture gauge was developed and perfected in China, the neutron moisture gauge was not only applied to measuring moisture content of soil and material in blast furnace, but also monitoring moisture content of farmland, saving water for irrigating farmland, monitoring safety of embankment, controlling density and moisture content of earth base and quality of concrete automatically. And moisture content of pottery, wet glass fibre materials, coke and coal were also measured by the neutron moisture gauge^[3].

In this working, the development of neutron moisture gauge, in China, is introduced according to measuring mode.

2 In-hopper neutron moisture gauge

The theory of neutron slow-down and diffusion is applied to design of in-hopper neutron moisture gauge. A thermal neutron field is come into being around neutron source. A spatial distribution of the thermal neutron is variable as variation of moisture content. When moisture content is high, the distribution is narrow and high. When moisture content is low, the distribution is wide and low. Once a detector of thermal neutron is reasonably designed and located around the neutron source, the counter of the detector is increased with increasing moisture content. The Fermi age theory and two-group diffusion theory mode were traditionally selected as theoretical treatment method of the in-hopper neutron moisture gauge. At Nanjing University, the three-group theory mode was selected to treating the in-hopper neutron moisture gauge. The numerical calculation results agreed with experimental data excellently. Through the numerical calculation for pellet and coke material, a new system which is constituted of a ring neutron resource and a neutron detector was proposed and can better improved the performance of in-hopper neutron moisture gauge. And a super-thermal neutron moisture gauge was also proposed.

For the in-hopper neutron moisture gauge which is developed and generated in China, there mainly were two kinds of instruments: one was constituted of point neutron source and neutron detector, and the other was constituted of ring neutron source and neutron detector. For the first, the source was located in front of neutron

detector and also side face of the detector according to requirement of measuring moisture content. For the second, the source was rung on the neutron detector and adjusted to being any location^[4,5]. Fig. 2 is schematic diagram of in-hopper neutron moisture gauge for pellet and coke material.

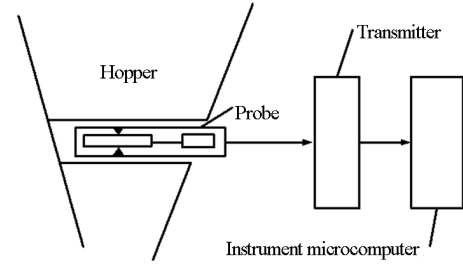


Fig. 2 Schematic diagram of in-hopper neutron moisture gauge for pellet and coke material

There were immovable and portable in-hopper neutron moisture gauge in China^[6-9]. The immovable in-hopper neutron moisture gauge was mainly applied to automatic production in large-scale industry. Typical industry was some steel corporation of China, in which the moisture content is measured in pellet, coke and coal material^[10,11]. In China, the portable in-hopper neutron moisture gauge was typically applied to measuring moisture content in farmland. The aim was to view distribution and dynamic variation of moisture content with variation of farmland deepness, holding and vaporizing water content in farmland. It was also applied to investigate water required for crop, manage moisture content of farmland and save water for irrigating farmland. Fig. 3 is a schematic diagram of in-hopper neutron moisture gauge for measuring moisture content in farmland. The neutron moisture gauge is inserted into the soil passing through the pipe and can view the distribution of moisture content. Fig. 4 shows an in-hopper neutron moisture gauge of a type SHD - 1 generated by Jiangsu Academy of Agriculture Science and applied to measuring moisture content in farmland. Fig. 5 shows neutron soil moisture gauge of a type CS830.

When the in-hopper neutron moisture gauge was applied in industry and agriculture, variation of density influenced precision of measuring moisture content. At middle of 1980s, the in-hopper neutron moisture gauge with density compensation was developed and generated in China. γ source and detector was assembled in the in-hopper neutron moisture gauge and was used to measure the density of material, so that it correct the influencing of density variation. The technology impelled more development of the neutron moisture gauge in China.

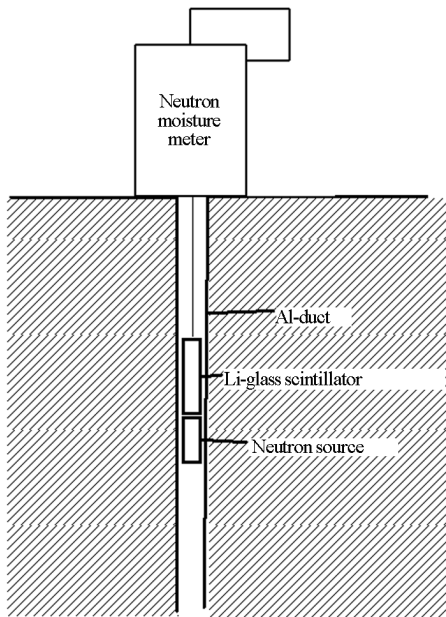


Fig. 3 Schematic diagram of in-hopper neutron moisture gauge for measuring moisture content in farmland



Fig. 4 In-hopper neutron moisture gauge of a type L250-D



Fig. 5 Neutron soil moisture gauge of a type CS830

3 Surface neutron moisture gauge

The surface neutron moisture gauge was also designed according to theory of neutron slow-down and diffusion in material. When neutron beam into material from surface of material and is slow-down and diffusion in the material, part of neutron is reflected back to surface and is received by the detector located at surface of material. The reflected neutron is mainly thermal neutron and increased with increasing moisture content. The thermal neutron detector, for example BF_3 counter and Li-glass scintillator, was selected in the surface neutron moisture gauge. The neutron source and the thermal neutron detector were both put in a sensor located at surface of material. If the in-hopper neutron moisture gauge is not suitable for some field, the surface neutron moisture gauge is very useful for measuring moisture content.

The surface neutron moisture gauge, developed and generated in china, was constituted of a point neutron source and a thermal neutron detector as a surface sensor located at surface of material. Fig. 6 is a schematic diagram of surface neutron moisture gauge. In Hangzhou Ferroalloy Factory, the surface neutron moisture gauge was applied to measuring moisture content in coke material. The surface neutron moisture gauge was typically applied on earth base work of road, railway and airport in china. To ensure quality of these earth base works, it is necessary to measure and check the wet density and moisture content. To achieve measuring wet density and moisture on constructing field, the nuclear-earth-base-density moisture-gauge of type NDH-A was developed by Hunan Institute of Communication Science. The NDH-A was constituted of a point neutron source and Li-glass scintillator^[12-14]. Other surface neutron moisture gauge, for measuring a capability of road pressed by vibratory road roller, was developed by Hangzhou Machine Institute. Fig. 7 shows a neutron moisture gauge of a type ZSY-3000. The surface neutron moisture gauge was typical applied to safety monitoring of embankment. It can inspect effect of leakage and variation of leakage coefficient for wall of defending leakage on riverbank. It can found out spatial distribution of moisture content in riverbank^[15]. The surface neutron moisture gauge, generated in China, was provided with density compensation. It was not only applied to measure density, but also carried out density compensation for measuring moisture content.

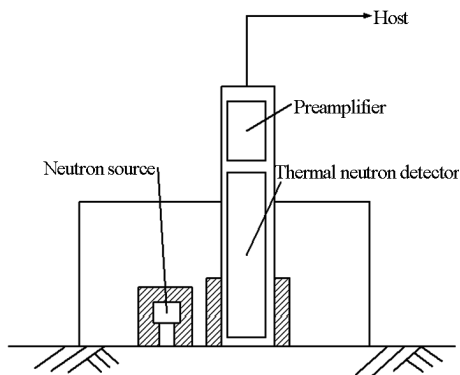


Fig. 6 A schematic diagram of surface neutron moisture gauge



Fig. 7 Neutron moisture gauge of a type ZSY-3000

4 Transmitted and scattered neutron moisture gauge

Transmitted and scattered neutron moisture gauge is sampling. The system is constituted of device of derivative neutron beam and neutron detector. The measured sample is located between the device and detector. According to attenuation rule, transmitted intensity of the neutron beam is delayed when the neutron beam pass through the sample. The transmitted intensity is decreased with increase of moisture content. So that, the moisture content in sample is determined with the transmitted intensity of the neutron beam. The derivative neutron beam is thermal neutron beam^[16-20]. Fig. 8 is a schematic diagram of transmitted neutron moisture gauge. The scattered neutron moisture gauge is based on the transmitted neutron moisture gauge. The neutron detector is shifted to side of sample and receives the neutron scattered with sample. The count of scattered neutron is direct proportion with the moisture content in sample. If the transmitted neutron moisture gauge is not suitable for some field, the scattered neutron moisture gauge is very useful for measuring moisture content.

When a point neutron source was put in a moderator of paraffin, the three-group theory mode was

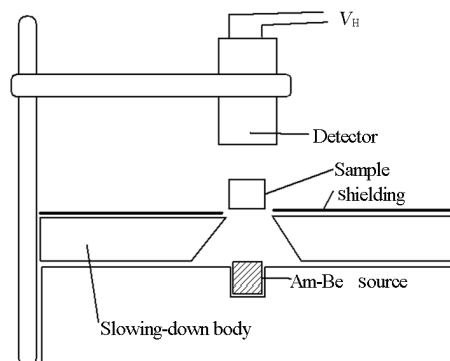


Fig. 8 Schematic diagram of transmitted neutron moisture gauge

selected to calculating the spatial distribution of thermal neutron in the moderator, at Nanjing University. Based on the calculation result, the device with well model which is used to derivate a beam of thermal neutron was designed. And the transmitted and scattered neutron moisture gauge was developed at Nanjing University as a sampling neutron moisture gauge. The device was applied to many domains in China. The nuclear-density moisture-gauge was developed, when a γ source was put in well.

The sampling neutron moisture gauge has characteristic of speediness and non-destructibility and substitute the traditional drying, in industry and agriculture and in laboratory, for example sampling from farmland, from material in blast furnace, from material of fiberglass and from material of pottery.

5 Conclusion

In development of neutron moisture in China, Am-Be neutron source was basically used, because γ radiation emitted from the neutron source is week and its lifetime is enough long (423 years). The Am-Be neutron source was designed with point and ring source according to requirement of neutron moisture gauge. The neutron detector used to neutron moisture gauge was mainly generated in China, for example BF₃ and ³He counter and Li-glass scintillator. Table 1 shows the moisture region and measuring precision of neutron moisture gauge in China, according to measuring mode.

Table 1 The moisture region and precision of neutron moisture gauge in China

	In-hopper /(wt %)	Surface /(g·cm ⁻³)	Transmitted /(wt %)
Moisture region	4 ~ 14	1.4 ~ 2.2	4 ~ 12
Measuring precision	< 0.5 %	< 0.01	< 0.5 %

Note: wt % —moisture weight percentage in material; g/cm³—moisture density in material.

In 1980s and 1990s, the neutron moisture gauge was rapidly developed in China. And the neutron moisture gauge was recently applied to more domains^[21-30]. In industry and agriculture of China, measuring moisture content with neutron moisture gauge is one of routine measuring moisture content. On architecture, the neutron moisture gauge was introduced into measuring moisture content in architecture material.

Along with the development of neutron moisture gauge, the neutron gauge was also extended for measuring hydrogen content, element of large cross section and some physics parameter in China. The neutron gauge was applied to measuring hydrogenous index in rock sample, gadolinium content in material, specific surface area in cement production and thickness of steel plate etc. Fig.9 shows neutron moisture gauge of a type HDY5040A which measure moisture content in silicon sand, sandstone power and alkali material.

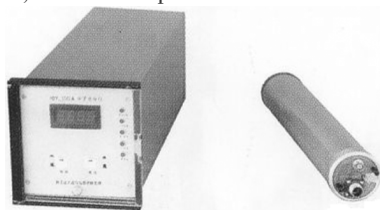


Fig. 9 Neutron moisture gauge of a type HDY5040A

Recently, the technology of neutron measuring moisture content was also developed as the development and enhance of neutron measurement technology and as demand for measuring moisture content in some domain, in China. The neutron radiography was applied to service life of reinforced concrete structures, in order to visualize movement of water into the interface between steel reinforcement and concrete and into the fracture process zone ahead of a crack tip. It is finding out how water and harmful compounds dissolved in water are taken up into the porous structure of concrete by capillary action and diffusion or a combination thereof^[31]. The characteristic γ radiation, based on PG-NAA, was also used to measuring all-water of coal in coal industry. A interfere of different elements is avoided and higher precise of measuring moisture content is obtained. Pulsed neutron generator and BGO detector was used to the method^[32].

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