A New Grouting Method Based on Measuring Dynamically Water-Pastern Ratio

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***Abstract* - In order to measure accurately water-pastern ratio of cement fly ash grout in grouting engineering, a nuclear device of measuring water-pastern ratio is studied. It is based on γ-rays weakening characteristic when γ-rays go through cement fly ash grout, the weakening amount is relative to grout density. When rays intensity, ray-location and cement fly ash gout thickness are defined, the grout density and water pastern ratio can be calculated by a mathematical model. Experimental results show that the device has good stability, high precision and sensitivity, quick response, and it can work normally under high temperature, damp and dust environment.**

Keywords - Radiation detector; Density; γ-ray; Grouting; Transducer

I. INTRODUCTION

In the recent development of large and medium hydropower stations, pulverized fuel ash mixed with cement grout is used in dam curtain grouting and foundation reinforcement grouting and its merits include saving cement, reducing the construction cost and improving anti-corrosion [1]. There are many factors affecting the process and result of grouting, such as properties of cement, grouting method and technology, and even quality of bore hole, while the most important and controllable factors are pressure, flow and water-pastern ratio. In order to improve the quality of grouting and reduce man-made errors in registration during grouting, it is recognized that auto-recorder system must be used during grouting process. To maintain this important issue, some new construction standards of hydroelectric power station were made in China, under which only registration made by the auto-recorder can be accepted by the construction owner. Grouting pressure and flow can be measured accurately and dynamically by most auto-recorder systems, while it is difficult to measure water-pastern ratio accurately and dynamically. As a result, the registrations of water-cement ratio are still hand-written. In order to solve this problem, the authors invented a new transducer applying nuclear density transducer in the present study, which is suitable for almost all types of cement pulverized fuel ash grout with different water-pastern ratio performed in dam curtain grouting and foundation reinforcement grouting.

II. BASIC THEORY

As is known to all, some of the photons will be absorbed while γ–ray passing through the cement pulverized fuel ash grout. The higher the density is, the more the amount of photons absorbed by the grout will be, and the less the amount of photons passing through the grout will be. The relation between the amount of the photons passing through the grout and the density of the grout can be expressed as following [3, 4]:

$$N_i = N_0 \cdot \exp\left(-\mu_m D\rho\right) \tag{1}$$

where N_0, N_i are the amount of the photons emitted by the source and passing through the grout, respectively; D is the diameter of the tube through which the grout passing (in meter); ρ is the density of the grout (in g/cm³); and μ_m is the absorbing coefficient. Under the condition of constant γ-ray source and constant tube diameter, the density of grout can be calculated based on the density of water [4]:

$$\rho_g = \rho_w + \left(\ln N_w - \ln N_g\right) / \mu \tag{2}$$

where ρ_g, ρ_w are density of grout and water, respectively; and N_g, N_w are the amount of photons passing through grout and water, respectively; $\mu = \mu_m \cdot D$

Water-pastern ratio is proportion to the density of cement pulverized fuel ash grout, so water-pastern ratio can be calculated from the grout density. With relative high stability and long half life period, Cesium-137 was used as constant γ-ray source, together with a photomultiplier tube to detect the photons passing through the grout. Photons absorbed by the photomultiplier tube were transmitted to electric pulses. The amount of the electric pulses transmitted from the photons is proportion to the amount of the photons detected by the photomultiplier. After amplified, the amount of the electric pulses can be recorded by microcomputer.

As it is nature radiation source, the radiation intension of cesium-137 is not affected by circumstance condition such as temperature, humidity, noise and intense electric field, which are characteristics of grouting field conditions

[2]. Due to this fact, γ-ray can be used to make grout density transducer with high accuracy and stability.

III. STRUCTURE OF THE DENSITY TRANSDUCER

Radiation source. Nature cesium-137 was used as radiation source of the density transducer. Intension of the source is 5millicurie with γ-ray of 662kilo electron volt. The source was sealed in the stainless steel container with double walls (fig.1). Within the wall, lead was filled to prevent γ-ray radiated freely. γ-ray can only emit out through a small hole with diameter about 8mm passing through the double walls and the lead when the transducer is running, and the hole will be closed in other case. With the strict control, screening capacity of the transducer was prior to NHMRC (National Health and Medical Research Council) standard.

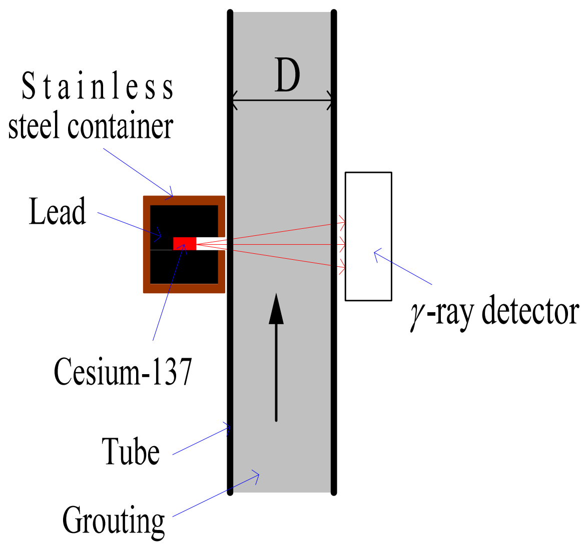

Figure 1. Principle frame of the new water-pastern ratio transducer

Radiation detector. Radiation detector consists of γ-ray detector and preamplifier. The main function of this part is to absorb photons, transform the photons to electric pulses, and amplify the electric pulses. The electric pulses were finally recorded by the microcomputer [5-11].

Grouting tube. Grouting tube used in density transducer was a casing tube of 300mm long and 168mm in diameter (fig.1). Grout thickness D affects measuring accuracy directly. Theoretically, D value should be determined by the density of grout, for grout with high density (low water-pastern ratio) a small D value should be selected, otherwise tube with big D should be used. If the diameter of the tube is too small, the amount of photons absorbed by the grout will be very little, and it will be quite difficult to detect the change of the water-pastern ratio of grout, as the change of the amount of photons absorbed by the grout is very little in this case. On the other hand, if the thickness of grouting is too big, the amount of the photons passing through the grout may be too little to affect the accuracy.

Accordingly, with an optimum value of thickness of grout, measurement accuracy will be best under this grout thickness [6]:

$$D_{opt} = 2/(\mu_m \rho) \tag{3}$$

For cesium-137, $\mu_m = 0.0068m^2/Kg$, and water-pastern ratio is controlled in the range from 0.5:1 to 0.8:1 in practice, in which ρ varies from 1559kg/m^3 to 1756 kg/m^3 ($\rho_{0.5:1} = 1756kg/m^3$ and $\rho_{0.8:1} = 1559kg/m^3$). From equation 3, optimum value of grouting thickness should be in the range from 0.15m to 0.24m. As it is not convenient to change the tube of different diameter frequently in practice, the tube with bigger diameter which can maintain high accuracy of the transducer with the thickest grouting was used in practice. Casing tube with a diameter of Φ168 was used as the grouting tube between the radiation source and the γ-ray detector for grout passing through to maintain the best accuracy of the density measurement of grout with water-pastern ratio from 0.8:1 to 0.5:1 which is the most important type for its large dosage in grouting practice.

From equation2, the absorbing coefficient can be calculated as following:

$$\mu = \frac{\ln N_w - \ln N_{sg}}{\rho_{sg} - \rho_w} \tag{4}$$

Where ρ_w and ρ_{sg} are the density of water (ρ_w=1.000g/cm3) and standard grouting (with a cement-water ratio of 1:1 and ρ_{sg}=1.519g/cm3), respectively. N_w and N_{sg} are the amount of the photons passing through water and standard grouting, respectively. The electric pulse I_w (or I_{sg}) caused by the photons arrived the γ-ray detector, which is proportion to N_w (or N_{sg}),wa amplified by the preamplifier and measured by ammeter. This means that the absorbing coefficient μ of one nuclear density transducer can be calculated by following equation:

$$\mu = \frac{k(\ln N_w - \ln N_{sg})}{\rho_{sg} - \rho_w} \tag{5}$$

where k is coefficient of photon-electric pulse transfer. Density of grouting can be calculated as following:

$$\rho_g = \frac{\ln I_w - \ln I_g}{\mu} + \rho_w \tag{6}$$

As density of water is known, only density of standard grouting should be measured in calibration. In field calibration, standard grouting should be pumped through tube for longer than nine minutes after the calibration key was pushed, and LJ-Ⅲ auto-recorder will record all the correlative parameters and calculate μ value automatically. The water-cement ratio of the grouting passing through the detective tube was calculated automatically by the microcomputer within LJ-Ⅲ auto-recorder during grouting.

IV. FIELD EXPERIMENTS

The field experiments were carried out in Hongjiadu hydroelectric power station. Tab.1 is part of the measuring results, where water-pastern ratio is the quality ratio, the unit of the grout density is g/cm^3, and the unit of time is minute.

TABLE I RESULT OF NUCLEAR DENSIMETER MEASURING WATER CEMENT RATIO DYNAMICALLY

W/P=0.8:1 ρ_g=1.559			W/P=0.7:1 ρ_g=1.613			W/P=0.6:1 ρ_g=1.677			W/P=0.5:1 ρ_g=1.756		
time	W/P	ρ_g	time	W/P	ρ_g	time	W/P	ρ_g	time	W/P	ρ_g
005	*.***	*.***	020	2.11	1.281	035	1.30	1.421	050	0.88	1.570
010	2.90	1.209	025	2.02	1.292	040	1.01	1.514	055	0.80	1.610
015	2.89	1.213	030	2.00	1.294	045	1.01	1.514	060	0.80	1.611

Asterisk in the table was caused by unstable of the water-pastern ratio at the beginning of grouting (within 5 minutes). Water-pastern ratio was changed 4 times from 5 minutes to 60 minutes after the beginning of the grouting. The first line in the table is the density measured with conventional method and true value of water-pastern ratio of grout. Density and water-pastern ratio below the first line were measured by the nuclear water-pastern ratio transducer. It can be seen that results measured by the nuclear water-pastern ratio transducer are consistent with the true value, except the first minutes shortly after density of the grout was changed.

V. CONCLUSIONS

Water-pastern ratio is one of the most important parameters affecting the quality of cement pulverized fuel ash grouting. The new density (water-pastern ratio) transducer can measure the density dynamically and accurately, and the most important is that it will never be affected by grouting velocity, pressure, and temperature etc. Having been used in curtain grouting of Hongjiadu hydroelectric power station constructions, the new density transducer has proved to be reliable and stable transducer. The main advantages of the new density transducer are:

(1) The transducer is installed outside of the tube and has no contact with the grout. The non-contact measuring method is very convenient and can not be affected by the grout factors, such as velocity, pressure, temperature, and viscosity.

(2) Due to the high accuracy of 0.005g/cm^3, this type of grouting water-pastern ratio transducer has wide field of application for curtain grouting and reinforcement grouting.

It should be noted that half life period of the radiation source cesium-137 used in the transducer is 30 years; thus the radiation source must be controlled strictly.

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