GAMMA-REFLECTION DENSITOMETER FOR THE QUALIFICATION OF CONCRETE SHIELDING

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In determining the density of materials with conventional methods, first the mass and volume of the sample obtained from the materials are determined, then the density index is calculated as the ratio of these two values. This density of the sample represents the overall density of the material and is valid only in case of homogeneous materials. Often minor inhomogeneities may occur in the material, however, we know that the extent of such inhomogeneities is small, and it is only the overall density of the material which interests the User.

With the conventional method the overall density could be determined only by calculating the average density of samples obtained from more points of the object at the expense of heavy destruction by sampling. In most cases the destruction of the object is undesirable.

In other cases, considerable inhomogeneities or discontinuities are found in the material, the extent and distribution of them are unknown. In such cases, the localization of the discontinuities with the conventional method would require in the worst case a cutting up of the whole material.

A nondestructive measurement method based on the principle of gamma reflection is a solution to the practical problem of determining average density and discontinuities in cases where accuracies below 1% and measurement beyond a depth of 10 to 12 cm are not required such as e.g. in building industry and road construction.

In some fields, this method offers a quick and convenient technique with, however, less accuracy as compared with the conventional method while in other cases, it permits determinations which cannot be made by the conventional method. The principle of gamma reflection can be advantageously used where the measured object is accessible only from one side. Namely, in this method, the radiation source and the detector are placed on the same side of the wall to be measured (Fig. 1a).

In nuclear power plants, the wast majority of concrete walls are erected for shielding purposes, e.g. in the Paks Nuclear Power Plant, Hungary, the volume of the concrete shielding in the first two units amounts about 100 000 m^3. In case of these walls, it is of special importance to ensure the specified density, homogeneity, and continuity. A not negligible part of such defects can be found in the external surface layer of a thickness of 10 to 15 cm of the walls. The

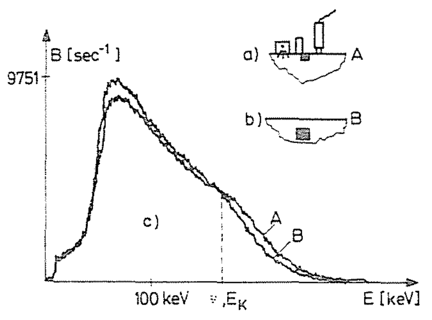

Fig. 1

method based on the principle of gamma reflection is suited to detect such defects. Encouraged by the above mentioned facts, we developed the measuring device described here. It is worth mentioning that other applications of the measuring device are also possible.

Gamma-reflection densitometer

The device developed consists of two main units (Fig. 2.) such as the measuring part including in addition to the radiation source and detector the required shielding in optimum geometry, and the analyzer.

The optimum set-up of the measuring part was determined by a trial in constructing and measuring practical arrangements to determine the optimum detector source distance, the optimum radiation source, and the minimum required thickness of the shielding. 17 cm was obtained as the optimum detector-source distance, and Cs-137 isotope was found to be the best radiation source. The weight of the measuring part was obtained as 13 kp for minimum shielding wall thickness.

Theoretical calculations were also made using a computer programme based on the Monte-Carlo method to prove that the above geometry was approximately optimum. A comparison of the results obtained by both methods and/or the flow diagram of the model programme will be discussed later in detail.

The other unit of the device, the analyzer, can be operated from both mains and battery. It can be operated continuously for minimum 24 hours without changing the batteries. It is a portable unit of a weight of 4 kp. The signal of the scintillation detector can be processed both analogously and digitally, and also the display may be both analogue and digital. The Block Diagram of the device is given in Fig. 2. Considering the high electric power demand of digital signal processing and display (conventional TTL), a continuous 24-hour operation could be achieved only by the use of low-consumption LCD displays and MOS integrated circuits. The digital signal processing increases the accuracy of measurements. With the source of an activity of 5.4 mCi, the time required for a measurement is 10 to 100 seconds. As seen in the Block Diagram, the mode selector switch of the device permits adjusting six different modes of operation, part of which serving for calibration and control while another part for actual measurements. In the Block

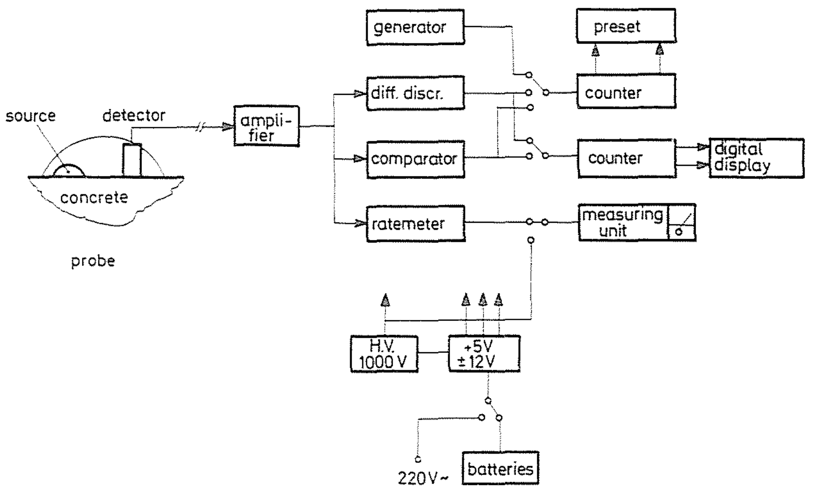

Fig. 2

Diagram, two counters can be seen, one for time and number of counts while the other counts the signals of the differential-discriminator and comparator. The device can be used as a single-channel as well as a two-channel analyzer and thus it is suited for simple energy spectral analyses.

Field of application

As possible applications, first of all the qualification of the concrete walls as biological shielding of the Paks Nuclear Power Plant has been taken into consideration:

a) The device is suited for densitometry where the required accuracy lies above 1%. The device measures the average density within a volume of about 2 dm^3 and supplies information on the quality of the material (in case of standard concrete) to a depth of 10 to 12 cm.

b) The device can be used to detect air inclusions and rests of wooden forms in the concrete as well as reinforcements or the lack or reinforcement (Fig. 3a).

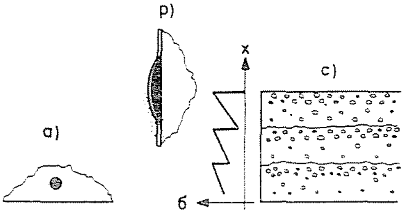

Fig. 3

c) Shot is added to concrete to increase the density. While compacting with vibration, these shots keep sinking more and more deep thus density of the surface layers is reduced. This segregation is definitely detected by the device (Fig. 3c).

d) A steel cladding is provided for some of the concrete walls. The device can be ideally used to detect undesirable air gaps between the steel cladding and the concrete. Air gaps of a thickness of 0.4 mm are weel detected by the device under a steel cladding of a thickness of 4 mm (Fig. 3b).

In the first three cases, the range of detectability i.e. the depth of measurement is 10 to 12 cm calculated from the surface. Information on the properties of the material can be obtained within this range by means of the device.

The computer model

The Flow Sheet of the computer model set up to confirm the practical measurement results can be seen in Fig 4. The programme was written in BASIC language for TPA and PDP-11 computers. The programme was run on the PDP-11 computer. There is a statistical fluctuation in the number of photons entering the detector, the magnitude of unit standard deviation being $\sqrt{N}$, the square root of the number of photons entering. Accordingly, the programme should be run for minimum 10 000 photons entering (in this case, the unit standard deviation would be 1%). However, the run time is of an order of magnitude of hours even in case of 1000 photons and the unit standard

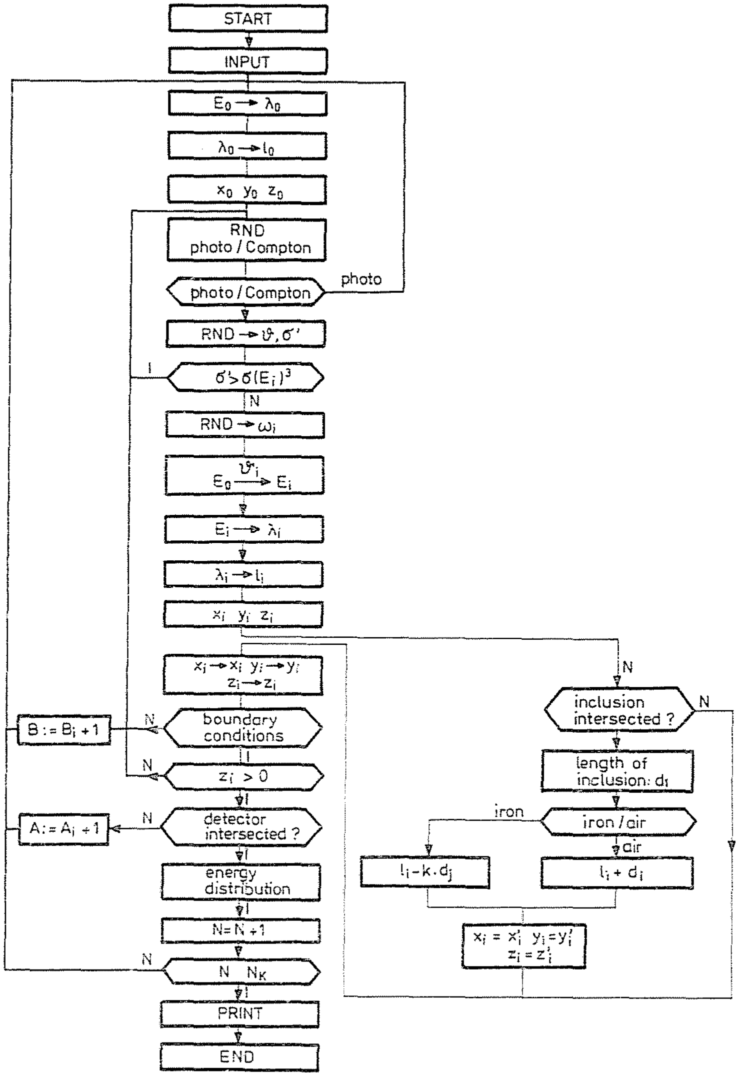

Fig. 4

deviation is about 3%. So far all results have been obtained under such conditions. The two energy spectra given in Fig. 5, one of which obtained as a result of actual experiments (measuring part plus multichannel amplitude analyzer) while the other was produced by the computer model, shall be evaluated accordingly. On the basis of the Figure, we may be right in saying that there is a good correlation between the two curves, a minor difference being only at the ranges of higher energies of the curves. However, if the accuracy of the model were further increased, the a priori long run time of the model would also increase so that the programme could be run for less photons per given time and, accordingly, the increased standard deviation would introduce new uncertainties. Thus, with realistic run times, the final model is the result of a compromise.

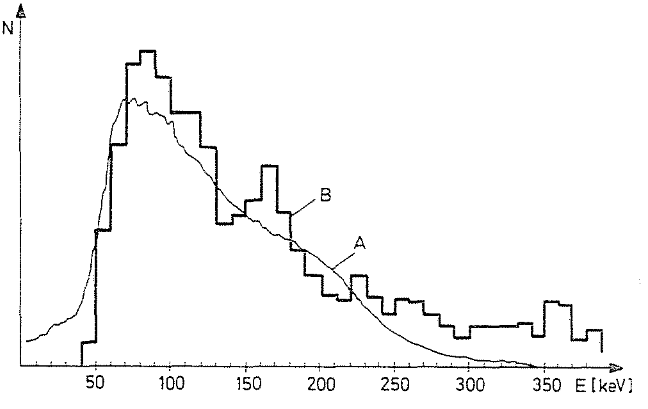

Fig. 5

The detailed computer programme sends a given number of photons of given energy with normal incidence to the surface. Assuming mean free path (λ_i) and using the Klein-Nishina formula:

$$d(\sigma_e S) = r_0^2 \, d\Omega \left[\frac{1}{1+\alpha(1-\cos\vartheta)}\right]^2 \cdot \left(\frac{1+\cos^2\vartheta}{2}\right) \times$$

$$\times \left\{1 + \frac{\alpha^2(1-\cos\vartheta)^2}{(1+\cos^2\vartheta)\cdot[1+\alpha(1-\cos\vartheta)]}\right\},$$

the computer uses the Monte-Carlo method to draw the new direction of the photon and to calculate the place of new scattering as well as the new energy of the photon after scattering by means of formula

$$E' = \frac{E_0}{\frac{E_0}{0.51}(1-\cos\vartheta)+1}.$$

For the new energy, the computer selects the new free path (λ_i, l_i) while continuously testing whether or not the surface is intersected by the path of the photon, and if intersected, whether this intersection coincides with the detector? If the photon gets into the detector, it will increase the content of a given register by 1 according to its energy. Finally, the content of these registers corresponds to the energy spectra obtained by means of the multichannel amplitude analyzer in practice. The programme is suited to take into consideration the case of air inclusion in the concrete.

Depth and size of inclusion as inferred from the energy spectrum

The nature of a possible defect in the material can not be inferred from the measurement of one single parameter i.e. the change of the number of counts; in this way, it can only be determined that the quality (density) of concrete in the point tested differs from the specification.

The densitometers we have known so far measured only this single parameter i.e. the change of the number of counts.

If we need additional information on the nature of the defect, then the measurement of some additional parameter is required, since by the knowledge of one single measured data, it is impossible to distinguish e.g. between the following two cases whether there is a smaller inclusion near the surface (Fig. 1a) or a larger inclusion at a considerable depth in the material (Fig. 1b). It may occur that the same change of the number of counts is measured in both cases. An answer to the question as which of the two cases is faced can be obtained only by measuring an additional parameter, e.g. by investigating the energy spectrum. In case of air inclusions, the number of counts increases in both cases but if the air inclusion lies near the surface, the path of the photons will be shorter and thus photons of higher energy will predominate among the photons entering the detector. Accordingly, increased number of counts will be obtained in this case in the higher energy ranges, and inversely, the number of counts will increase in the low energy ranges if the air inclusion lies at appreciable depth. Thus, the energy range is divided in two parts by the given point (E_k). The use of a complicated multichannel amplitude analyzer is unnecessary; a two-channel analyzer is suited for the purpose and this is available with the device developed by us owing to the digital signal processing.

The energy spectra for both cases are shown in Fig. 1c. A more detailed analysis of the energy spectrum may supply additional information on the properties of the material and our investigations are continued in this direction.

Summary

A gamma-reflecion densitometer had been developed by the auther. By analysing the gamma-spectra conclusions can be drawn about the inclusions in the concrete concerning their largeness and their depth. The device can be used in industry or other fields too.

References

1. ROBLEY D. EVANS: The atomic nucleus gamma rays. Chapter 8 (p. 8–191)—(p. 8–215). McGraw-Hill Book Co. Inc.
2. ROBLEY D. EVANS: Handbuch der Physik. Vol. XXXIV. Compton Effect. (p. 218–298). ed. Springer-Verlag, OHG, Berlin 1958.
3. NAGY, L. GY.: Radichemistry and Isotope Technology. Chapter IV. 3. Interaction between Ionizing Radiation and Material. (Hung.) Tankönyvkiadó, Budapest 1975.
4. KOVÁCS, I.: Current Problems of Densitometry. (Hung.) Mérés és Automatika, p. (29–35), 1977/1.
5. Radiometric Testing of Density of Concrete for Radiation Shielding. (Preprint) Brno, Czechoslovakia, October 5–9, 1970.

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