Simultaneous dynamic neutron and gamma radiography

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Equipment for dynamic neutron and gamma radiography has been developed at the 4.6 MW research reactor in Budapest, using thermal neutrons and gamma radiation obtained from the reactor. Radiography images are detected by scintillator screens and by low-light-level TV cameras, providing the possibility of visualizing medium-speed movements inside the investigated objects. The images are displayed on monitors and stored on video recorders. Some applications for nondestructive investigations are given.

Keywords: neutron radiography, gamma radiography, image detection

The transmission properties (attenuation coefficients) of neutron and gamma radiation are different, thus providing complementary information on the internal composition of an investigated object. Neutrons are transmitted by the majority of the technically important metals (e.g. aluminium, iron, steel, copper) with little loss in intensity, whereas hydrogen-containing materials such as water, oil or several types of synthetic compounds cause a significant decrease in the intensity of the neutron beam. On the other hand, the intensity of gamma radiation is strongly attenuated by the heavy elements, and it is transparent to hydrogen-containing light materials.

Although neutron and gamma radiography are used in separate laboratories, certain investigations require the simultaneous application of the two methods, especially dynamic radiography investigations when the inner structure of an object is studied during operation.

We have recognized the possibility of using neutron and gamma radiation obtained from the same source, i.e. from a thermal channel of a reactor, and have constructed a dynamic radiography installation applicable for simultaneous neutron and gamma radiography. In this paper we give a description of the equipment and some applications to nondestructive investigations.

Equipment

Beam formation

Figure 1 illustrates the arrangement of the dynamic radiography installation built at a horizontal channel of the 4.6 MW WWR-SM type research reactor in Budapest. A 1000 mm long pin-hole type primary collimator (see Figure 2) is placed in the reactor channel between the water tank and the beam shutter. It consists mainly of iron to collimate the neutron and gamma rays simultaneously. The diameter of the beam is 100 mm at the face of the reactor wall. The investigated objects are placed at a distance of 1200 mm from the reactor wall. The beam is guided to this position by a secondary collimator prepared from B₄C. The collimation ratio \((L/D) = 100\), the
diameter of the beam is 150 mm and the neutron flux is \( \sim 10^6 \) neutron/cm\(^2\) s at the object plate.

A special collimator is placed between the reactor wall and the secondary collimator, having a window of continuously variable diameter between 100 mm and zero, acting as a beam shutter. This is prepared from lead. The advantage of this system is that the irradiated object's surface can be optimized by its use, thereby decreasing any unnecessary scattered radiation from the object as well as decreasing the biological background radiation. Investigated objects of a maximum weight of 50 kg and of maximum dimensions 600 \( \times \) 1200 \( \times \) 1500 mm can be moved in the beam by a remote control mechanism.

**Imaging system**

**Converter screen**

For neutron radiography a \(^{4}\)Li doped ZnS (NE 426) screen is used; for gamma radiography image detection a ZnS screen (Perlux LS90). A Trimax 3 T8 screen is also used in the imaging system which is sensitive both to neutron and gamma radiation. Although the sensitivity and resolution of it is worse than that of the two others, it provides a means of obtaining an image of both the metal and hydrogen-containing components of the investigated object on the same display screen.

**Camera**

The light obtained from the converter screen is turned by a mirror in order to avoid activation damage of the camera by the beam. The light is focused and its brightness is optimized by a remote controlled zoom optics system and it is detected by a low-light-level TV camera (TV 1121). The light sensitivity of the camera is \( \sim 10^{-4} \) lux and its imaging cycle 40 ms, thereby providing the possibility of visualizing medium-speed motions inside the object. The image sensor of the camera is fitted with a maximum light limit, in order to protect the camera against damage from unexpected high intensity light. However, this has the disadvantage that sometimes the most interesting parts - having lower transmission than the average - cannot be seen, if the automatic control optimizes the adjustment of the light integrated over the whole image surface. To avoid this an adjustable window system prepared from Cd for the neutron and/or Pb for the gamma beam is placed in front of the imaging system, thereby enabling one to obtain an image of only the most important parts, which would otherwise be quite dark.

**Visualization and storage of the radiography image**

The radiography images are visualized on monitors, and their video signals are led into a video mixer unit (TV 1738). In addition to the radiography images some physical parameters (e.g. temperature, measuring time, pressure) and a visual image of the investigated object may be displayed on the monitor. The important images are selected and mixed by the video mixer unit and are stored on a video recorder. Two arrangements have been constructed to detect the neutron and gamma image of the investigated object using the same beam: a completely simultaneous, and a semi-simultaneous configuration. The main characteristics of the two methods are as follows:

- **Simultaneous neutron and gamma radiography arrangement**

  The arrangement is shown in Figure 3. Two converter screens are placed after each other and the light is detected by two low-light-level TV cameras. The sequence of the screens is very important: the gamma converter screen should be placed behind the investigated object and behind this the neutron converter, otherwise the resolution of the gamma image is spoilt.

  The resolution of the gamma image is \( \sim 350 \mu \text{m} \) and that of the neutron image \( \sim 200 \mu \text{m} \).

- **Semi-simultaneous neutron and gamma radiography arrangement**

  The arrangement in this case is shown in Figure 4. Three
converter screens are placed on the same plate built into the light shielded unit containing the mirror and the zoom optics. The converters are moved into the appropriate position by remote control. The converters are changed within 12 s. The resolution of the gamma image is \( \sim 350 \, \mu m \) and that of the neutron image \( \sim 150 \, \mu m \).

**Applications**

**Investigation of fuel consumption meter**

The development of new generations of fuel consumption meters is an important task in order to decrease the fuel consumption of internal combustion engines.

Dynamic neutron and gamma radiography have been used in the development work of the prototype of a piston fuel consumption meter (Figure 5). The flow of the hydrogen-containing fluid was investigated by neutron radiography, while the motion of the pistons and other metallic parts could be checked by gamma radiography via the fluid. The use of these complementary methods enabled the cause of defective functioning of the investigated fuel meter to be revealed; it was shown that the fluid had leaked into the gearbox casing (see Figure 5b) as a consequence of a damaged gasket.

**Investigation of absorption-type refrigerators**

The study of refrigerators has been the main subject of our dynamic neutron radiography work in the past few years\(^5\). The high hydrogen content of the working fluid, being a mixture of water and ammonia, enables one to visualize the process of boiling in the bubble pump within the double walled pipe, and the condensation and transfer

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**Fig. 5** Piston fuel consumption meter (photograph from monitor): (a) visual picture, (b) neutron radiographic image. The arrow shows the fluid leaking into the gearbox casing as a consequence of defective functioning, (c) gamma radiography image. Dark vertical line is a marker.

**Fig. 6** Part of the tube system under the boiler of an absorption type refrigerator during operation: (a) neutron radiography image showing the tube filled up continuously by the working fluid, (b) gamma radiography image showing the coaxial tubes at the same time (photograph from a monitor; dark horizontal line is a marker)
of ammonia in the tube system. Gamma radiography can be used to check the internal welded joints and the pipe-end penetrating into the fluid tank which transfers the rich solution, since this is a determining factor of the starting flow conditions. Examples are given in Figure 6.

Investigation of bubble memory cassettes

Simultaneous neutron and gamma radiography of objects with unknown inserts is a very important application. As an example, Figure 7 shows the radiographic images of a bubble memory cassette. The neutron radiography image (Figure 7a) shows the plastic case and the gadolinium-garnet single crystal, whereas the gamma radiography image (Figure 7b) gives information on the coil system which generates the rotating magnetic field, and on the connecting metallic elements.

Conclusions

The thermal channel of a 4.6 MW WWR-SM type reactor has been used for dynamic neutron and gamma radiography. The results have proved that the reactor acts as an effective simultaneous neutron and gamma source. Two alternative arrangements have been developed: a completely simultaneous and a semi-simultaneous one. The latter installation is considerably cheaper and simpler as it is based only on one low-light-level TV camera. Furthermore, most of the investigated inner processes may be regarded as quasistationary processes, so the semi-simultaneous method gives sufficient information on the dynamics of the processes and may be regarded as completely simultaneous for most investigations.

Our method has proved to be an efficient tool for investigating various kinds of objects, giving complementary information taken at the same position and the same time. Simultaneous recording of external parameters and the radiographic pictures of the objects under investigation enables one to carry out a detailed study of the behaviour of processes inside objects as a function of these parameters, eg volume of the transport of cooling mixture, the temperature at different points of refrigerators, and so on. This possibility helps one to understand the main features of mechanical and thermodynamical processes developing in the given object. As a result, this method provides a unique means for a wide circle of manufacturers to improve their apparatus.

References


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