Available online at www.sciencedirect.com

ScienceDirect

Nuclear Energy and Technology 2 (2016) 37–41

www.elsevier.com/locate/nucet

The study of ultrasonic reflex-radar waveguide coolant level gage for a nuclear reactor

V.I. Mel'nikov*, V.V. Ivanov, I.A. Teplyashin

Nizhny Novgorod State Technical University n.a. R.E. Alekseev, 24, Minin Street, Nizhny Novgorod 603600, Russia

Available online 6 May 2016

Abstract

Results of experimental study of operation of ultrasonic reflex-radar waveguide level gage in water coolant at elevated parameters with pressure up to 18 MPa and temperature up to 350 °C are examined.

In contrast to the known waveguide level gages, traveltime of acoustic pulses along the waveguide from the radiator to the subsurface layer and back is measured in the level gage under study. Waveguide consists of two acoustically isolated waveguides – the radiating waveguide and the receiving waveguide. Waveguides of zero-order flexural waves and piezoelectric transformers operated at frequency of ∼800 kHz are applied. Processing of received signals is performed by microprocessor-based electronic circuit. Measurement uncertainty does not exceed ± 10 mm. Description of the experimental setup and the experimental methodology is provided.

The instrument works reliably and does not require introducing corrections of readings when coolant thermal physical properties change. The measurement instrument is intended for application in heat exchanging equipment in thermal and nuclear power generation.

Keywords: Ultrasonic reflex-radar waveguide level gage; Acoustic waveguide; Piezoelectric transformer; Water coolant operated at elevated parameters (350 °C, 18 MPa); Nuclear power installation; Power generating equipment.

Introduction

Instrumentation for control of coolant level constitutes the most vital components of control and safety systems of nuclear power installations (NPI).

Since coolant parameters examined here are practically extreme (temperature up to 350 °C and pressure up to 18 MPa at high levels of radiation) measurements of level represent a challenging technical task.

Numerous technical solutions and ideas were suggested for solving the above problem, although only small part of them was realized as working designs and even smaller fraction was practically tested.

In our opinion, acoustic instruments based on the use of metal waveguides are the most suitable type of instruments for solving the problem of water coolant level control in reactor facilities. Their application allows designing sensors with significant lifespans capable to conduct practically infinitely fast measurements and to work during extended time periods in the extreme conditions existing in nuclear power installations.

There exist two principally different optional configurations of the measurement system: the first option refers to level gages in the form of sampled data multipoint fluid signaling devices and the second option refers to the level gages allowing conducting continuous control of coolant level.

The first option is implemented on the basis of the system including several tens of waveguides each of which is equipped with piezoelectric transformer and is connected to sensitive element [1]. As the result multicomponent complex and expensive design is obtained which must be supplemented with appropriate versatile electronics and multi-wire connec-

* Corresponding author.
E-mail addresses: melnikov@nntu.nnov.ru (V.I. Mel'nikov), ivv@nntu.nnov.ru (V.V. Ivanov), ivantia@mail.ru (I.A. Teplyashin).
URL: http://www.aisnn.com (V.I. Mel'nikov)
Peer-review under responsibility of National Research Nuclear University MEPhI (Moscow Engineering Physics Institute).
Russian text published: Izvestia Visshikh Uchebnikh Zavedeniy. Yadernaya Energetika (ISSN 0204-3327), 2015, n.4, pp. 26-35.

http://dx.doi.org/10.1016/j.nucet.2016.03.007

tion cables. Advantage of multi-point signaling devices is associated with absence of the need to perform metrological certification of the instrument.

The second option refers to acoustic impedance level gages based on the measurements of attenuation (or delay) of acoustic pulses propagating along the extended-length waveguide when the latter is submerged into fluid [2,3]. The feature of acoustic impedance level gages distinguishing them from multi-point level signaling devices is their relative simplicity and, consequently, higher reliability and low cost. Significant drawback of these instruments is their interference with output signal in response to evolutions of physical properties of the controlled medium accompanied with changes of its temperature and pressure. Additional correction of the data is needed to eliminate this interference. Interferences due to condensate flowing down along the waveguide sensitive element above the interphase boundary and due to boiling resulting in the generation of vapor-gas bubbles within the fluid phase are also possible.

The above indicated drawbacks are associated with measurement methodology based on the determination of amplitude of received signal which is influenced by different factors ranging from the resistivity of communication lines to the ageing of waveguide elements. Significant improvement of quality of the instrument can be expected with substitution of amplitude measurements of acoustic signal with time-domain measurements.

Description is given in the present paper of the originally developed design of ultrasonic reflex-radar level gage and results of its experimental studies in the conditions which are close to the maximum extent to real operational conditions with wide variation of parameters of the controlled medium, i.e. water coolant at elevated parameters.

Principles of operation and design of reflex-radar level gage

The main idea of reflex-radar level gage consists in the location of the boundary separating fluid and gas media. Transfer of energy is performed in pulsed mode along the waveguide with the measured value being the traveltime of pulses from the radiator to the receiver. Such measurement principle is implemented in superhigh-frequency reflex-radar level gages where SHF energy pulses spreading along the waveguide are used. However, application of such level gages in nuclear power generation encounters significant difficulties associated with installation of SHF devices inside equipment of the primary cooling loop.

Attempts to apply reflex-radar technology on the basis of ultrasonic waveguides were undertaken in this country during 1970s but failed to demonstrate success [4,5].

Evident advantages of waveguide level gages with measurement channel on the basis of time-domain measurements compelled researchers to revisit this idea. As the result, efforts were undertaken to develop reflex-radar level gage using ultrasonic waveguides and pulsed signals.

The following two waveguides of flexural waves (as the most efficient radiators) are applied in the proposed technical solution: namely, the radiator and the receiver of ultrasonic pulses. Waveguides are arranged vertically parallel to each other. Hemicylindrical reflector with large number of bafflers designed in the form of undulated pipe sections cut longitudinally is installed along the whole length of the waveguides. Transmission of acoustic energy from one waveguide to another can take place only when the space between the waveguides and the reflector is filled with fluid. Layout of transmission of ultrasonic wave from the radiation waveguide to the nearest to it reflector baffler under the level of fluid and then to the receiving waveguide is shown in Fig. 1.

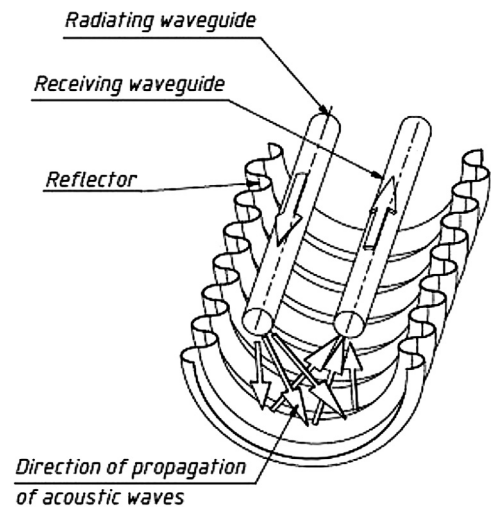

Fig. 1. Layout of propagation of ultrasonic wave from the radiating waveguide to the receiving waveguide.

Thanks to the physical properties of zero-order flexural waves efficient radiation of acoustic energy into the fluid occurs during their propagation along the waveguide submerged into the fluid. Practically complete transfer of energy of the flexural wave is achieved in the process in the contact of the waveguide with the fluid, for instance, for waveguide with diameter equal to 2 mm operated at 800 kHz frequency, along the length equal to just 30–50 mm.

Transfer of acoustic energy from the radiating waveguide in the fluid to the reflector and after that to the receiving waveguide takes place within the subsurface layer with 20–30 mm depth. Acoustic wave from the radiating waveguide penetrates the subsurface layer of the fluid in downwards direction at an angle and reaches the reflector. Following this, the wave undergoing repeated reflections from the reflector's horizontally oriented protrusions returns at the same angle in upward direction to the receiving waveguide shaping the signal on the receiving piezoelectric transformer. Fluid level is proportional to the time for ultrasonic pulses to travel along the waveguide to the subsurface layers of the fluid and back, i.e. it is determined using the time characteristic in accordance with reflex-radar principle.

Radiation of wave in the fluid takes place at the angle φ, determined from the triangle of the following sound velocities: flexural wave in the waveguide and lateral wave in the fluid [1]. For many fluids (including water) the angle at which the wave enters the fluid is approximately equal to 60°