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DIAGNOSTICS OF A PHASE STATE OF THE COOLANT IN PWR BY TEMPERATURE NOISES

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Abstract

The diagnostics of a phase state of the coolant under the normal operation of the reactor and at the pressure drop in it has been developed. The diagnostics is based on the registration and the analysis of temperature noises of the coolant. It ensures the control for appearing of a steam-gas mixture and for the level of the coolant in the reactor. At present the diagnostics system is being tested at NPP «Kozloduy» in Bulgaria.

1. INTRODUCTION

Diagnostics and control are fundamental tasks when ensuring NPP safety. Early detection and warning of damages, prevention of emergencies is the more effective way in principle for ensuring safety, efficiency and their increasing under the conditions of operating plant. The results of the analysis having been carried out on the existing diagnostics methods of appearing and development of steam-gas volume in the power reactor vessel have shown the absence of control mode for appearing of steam-gas volume at pressure drop of the coolant in the reactor plant. For the purpose of increasing NPP safety at the specified accidental situation the method of early diagnostics of appearing steam-gas volume in the reactor at pressure drop in it has been developed. The method consists of measuring an integral spectral density of noise capacity of the coolant's temperatures in a frequency band of 0.05-1 Hz by the height above the active core, as well as of determining their coherence function and estimating the coolant's state above the active core by variation of these values [1].

Detectors of the system are thermocouples which monitor the temperature in the reactor. The equipment of the system executes measurement of a spectral density of the rate of the coolant's temperature noise and their functions of coherence in a noise band of 0.05-1 Hz. The phase state of the coolant is determined by these values in the place of thermocouples' location, such as single phase, steam-water, steam-gaseous. The diagnostics of a steam-water phase and its evolution to a steam phase of the coolant in the reactor does not depend on its power and is carried out at the temperatures of 100-350°C. The diagnostics system allows the rate of the phase state changing of the coolant to be monitored.

2. DIAGNOSTICS SYSTEM

The diagnostics technique is based on the model where the measured temperature noise of the coolant is presented as the equation

$$\delta T = \delta k(T_s - \overline{T}_l) + (1 - \overline{k})\delta T_l$$

where:

δT – temperature noise of the coolant, T_s – steam temperature, $\overline{T}_l$ – average temperature of a liquid phase, $\overline{k}$, δk – weight coefficient and its noise, which are proportional to steam content. At boiling of the coolant with underheating-up when $1°C < \Delta T_s < 10°C$ (ΔT_s – underheating-up till the saturation temperature), the weight coefficient $\bar{k} << 1$. As it is seen from the equation, this results in increasing the temperature noise in comparison with the temperature noise of its liquid phase, at which $\bar{k} = 0$, $\delta k = 0$. At approaching the average temperature of the liquid phase of the coolant $\bar{T}_l$ to the saturation temperature T_s the portion of the weight coefficient $\bar{k}$ decreases because of the difference of $T_s - \bar{T}_l$, and the temperature noise of the coolant decreases. The tendency of decreasing the temperature noise is observed at boiling of the coolant in the whole volume, because the second term of the equation decreases as the weight coefficient grows. Under the saturation state the temperature noise of the coolant is minimum. It is seen, that the change of the coolant's phase state only is the basis of the diagnostics technique for its state.

Apparatus means of the system include:

standard thermocouples T located above the active core in different height, two as minimum, one thermocouple is located at the output of T core, and the second thermocouple – under the T cover;

weak-noising amplifier with filters of frequencies > 1 Hz;

computer of low level with microprocessor units of accumulation, information treatment and control for outer devices;

computer of upper level of PC AT-586 type (Pentium).

The amplifier and the computer of low level must be located to thermocouples as close as possible.

Each amplifier is connected via galvanic isolation which excludes the influence of the system on functioning of standard measuring channels, as well as via the capacity < 2 mkf for filtration of a direct component of T signal.

For the control of the system's serviceability either the devices actuating standard signals to the inlet of the amplifiers can be envisaged, or the control of serviceability is ensured by program means.

3. DETERMINATION ALGORITHM OF PHASE STATE OF THE COOLANT

Analogous alternating signals of thermocoupls T1 and T2 coming after amplifiers are transformed by the computer of low level into a digital form which is a temporal sequence of signals through constant intervals of time Δ. A digital statistical analysis of temporal sequences of T1 and T2 signals is carried out.

Autocorrelation and crosscorrelation functions φ_{11}, φ_{22}, φ_{12} of T1 and T2 signals are calculated.

Auto- and cross-spectral densities of capacity Φ_{11}, Φ_{22}, Φ_{12} are calculated.

Coherence function of two thermocouples γ_{12} is calculated.

Integral autospectral density of T1 and T2 capacity is calculated: $S_{11}=\int_{0.05}^{1} \varphi_{11}(f)df$; $S_{22}=\int_{0.05}^{1} \varphi_{22}(f)df$

The value of the integral autospectral density of capacity of each thermocoupls T is compared with its value having been measured before: $\frac{S_{11}(t)}{S_{11}(t_0)}$; $\frac{S_{22}(t)}{S_{22}(t_0)}$

The value of coherence function of two T is compared with its value having been measured before: $\frac{\gamma_{12}(t)}{\gamma_{12}(t_0)}$

At values of $\frac{S_{11}(t)}{S_{11}(t_0)} < 10$, $\frac{S_{22}(t)}{S_{22}(t_0)} < 10$, $\frac{\gamma_{12}(t)}{\gamma_{12}(t_0)} \geq 0{,}4$ the coolant is a single-phase.

At values of $\frac{S_{11}(t)}{S_{11}(t_0)} < 10$, $\frac{S_{22}(t)}{S_{22}(t_0)} \geq 10$, $\frac{\gamma_{12}(t)}{\gamma_{12}(t_0)} < 0{,}3$ steam-gas mixture is under the cover

At values of $\frac{S_{11}(t)}{S_{11}(t_0)} \geq 10$ steam-gas mixture is above the core.

At values of $\frac{S_{22}(t)}{S_{22}(t_0)} \leq 100$, $\frac{\gamma_{12}(t)}{\gamma_{12}(t_0)} = 0$ steam-gas mixture is under the cover

At values of $\frac{S_{11}(t)}{S_{11}(t_0)} \leq 100$ steam-gas-mixture is above the core.

Computation algorithms of correlation functions, spectral densities and correlation are standard as well as the programs of their computations [2].

Specifications of computer of low level are determined by a pass band of analogous signals by the amplifier and the accuracy of comparative spectral analysis.

Under the maximum error of 40% and the pass band of 0.05-1 Hz DAT must ensure:
quantum velocity (sample of the data) of 2 c^{-1};
duration of measuring of T=20 c;
number of samples of N=40;
low frequency of the signal – 0.05 Hz;
maximum number of delays m=4;
temporal increment Δ=0.5 c;
frequency increment Δf= 0.25 Hz.

REFERENCES

[1] Levadnyi V., et al., Patent Russia №96115951 (1996).
[2] Kim T.R., et al., SMORN-VII, Rep. 1.2, Avignon, France (1995)