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Analysis of Computer Code and Method Used in Thermal-Hydraulic Safety Justification of VVER Reactor Plants

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Abstract

This article presents the analysis of the calculation procedure and computer code KLAST used in calculations of the control rod dynamic characteristics during safety justification of water-cooled water-moderated power reactor plants. The code allows accounting for pressure differentials as a function of time occurred under the design conditions on the reactor core and on the drive extension shaft as well change of coolant density in the core. The code can be used to calculate dynamic characteristics of the control and protection system of control rod of VVER-1000 reactor types under the design accident conditions with rupture of the drive housing and to calculate the control and protection system of control rod dynamic characteristics during drop and damping in case of reactor damage during design accident conditions with pipeline break. In calculation, the control and protection system of control rod dynamic characteristics are determined versus time.

Keywords: reactor; thermal-hydraulic safety; calculation; dynamic characteristics; pipeline break; design accident.

1. Introduction

The code KLAST "Calculation of the control rod dynamic characteristics" is intended to calculate dynamic characteristics of the control and protection system of control rod (CPS CR) of VVER-1000 reactors during drop and damping under the design operation of the reactor (under the normal operating conditions (NOC), anticipated operational occurrences (AOO) conditions). The code can be applied to other reactor types wherein the CPS CR structural schemes are similar to those used for VVER-1000 [1] – [4].

The code allows accounting for pressure differentials as a function of time occurred under the design conditions on the reactor core and on the drive extension shaft as well change of coolant density in the core. Influence of change in the mechanical friction force in the CPS CR channel, elastic forces of the damper device springs depending on the CPS CR position coordinate (travelled path). Changes in hydraulic forces acting upon the control and protection system of absorbing rod (CPS AR) and extension shaft versus the CPS CR motion velocities and depending on the CPS CR position coordinates are taken into account [4].

The code is intended to calculate the process from the moment of drive de-energizing. The delay time from the beginning of signal generation to the beginning of CPS CR movement is taken into account separately in the analyses of design condition scenarios. If during CPS CR damping a margin of damping spring travel is completely taken up till the spring coils are linked, then there occurs mutual impact of the control rod against the FA guiding channel framework. For a case of mutual impact of the CPS CR with the guiding channel framework after the spring coils are linked up the code can be used only for determination of the CPS CR velocity directly before the mutual impact. This velocity is used in strength calculations [4] – [10].

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2. Statement of research problem and goal of research

The CPS control rods are intended to control reactor power and reactivity, and also to bring the reactor core to sub-criticality during NOC, AOO and design basis accidents. The CPS CR represents itself a system including the absorber rod engaged with the drive extension shaft.

Drive de-energizing during reactor damage results in free drop of the CPS CR. The path travelled by the control rod has two characteristic sections: a section of drop till the control rod contacts the damping device and a section of damping. Thus, the control rod is affected by the driving forces (weight of the dropping parts minus buoyancy force) and the resistance force (hydraulic forces, mechanical friction forces between the movable and immovable parts and the elastic deformation forces of springs). The hydraulic forces due to piston effect are formed on the extension shaft when it moves out of the drive cavity and on the absorber rod during displacement within the guiding channels [3], [4].

The process of CPS CR motion is described by the equation of movement representing itself a balance of forces acting upon the CPS CR in case of dropping and damping, and by the equation of hydraulics representing itself a balance of pressure differentials on the guiding channel sections [4]. The goal of this work is to analyze the calculation procedure and computer code KLAST used in calculations of the control rod dynamic characteristics during safety justification of VVER reactor plants.

3. Calculation procedure

Figure 1 presents the scheme for calculation procedure of CPS CR movement during reactor damage. This scheme shows conventionally one absorbing element and one guiding channel (CPS AR consists of 18 absorbing elements), drive, extension shaft and damper spring (combines characteristics of the fuel assembly (FA) cap and characteristics of the absorbing element suspender spring in the CPS AR cap) [4].

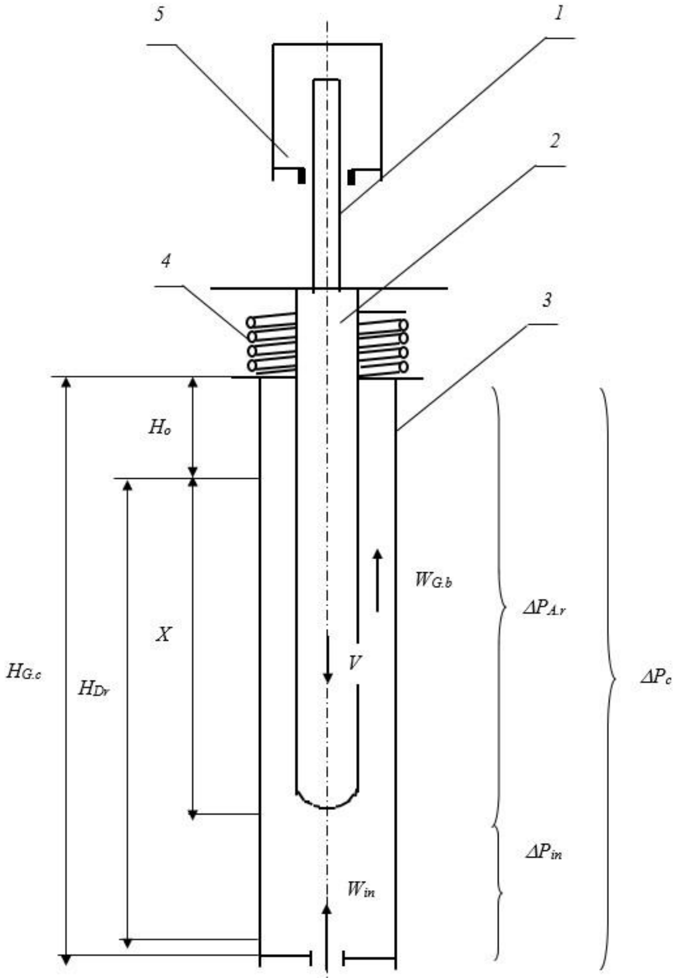

Fig. 1. Scheme for calculation of CPS CR movement: 1 – extension shaft; 2 – absorber rod; 3 – guiding channel; 4 – damper spring; 5 – pitch electromagnetic drive (ShEM).

Figure 1 shows the following characteristics used in the calculation procedure:

- general pressure differential on the core (ΔP_c) and the pressure differential components on the guiding channel inlet section (ΔP_{in}) (on the guiding channel tip and on the guiding channel tube section from the tip to the absorbing element) and on the absorber rod section ($\Delta P_{A.r}$);
- coolant velocity on the guiding channel inlet section W_{in} and distribution of velocity in the gap between absorbing elements and guiding channel in case of counter movement of the absorbing elements and coolant in the gap (V – drop velocity of the absorbing elements, $W_{G.b}$ – velocity of water in the gap);
- dimension of full height of the channel ($H_{G.c}$);
- dimension of drop height of the absorbing elements (H_{Dr}) that in a general view includes height of the free-fall section and the damping section till the spring coils are linked up;
- dimension of height of initial submersion of the absorbing elements within the guiding channel when the absorbing elements are in the upper position (H_o);
- current coordinate (X) in case of absorbing elements drop starting from the upper core boundary.

4. Mathematical model

The process of CPS CR motion [4] is described by the following equations:

$$(m_w + m)\cdot U = F_w + F_{Fr} + F_{Sp} + F_{E.s} + F_{A.r}; \tag{1}$$

$$\Delta P_{in} + \Delta P_{A.r} = \Delta P_c; \tag{2}$$

$$U = dV/d\tau; \tag{3}$$

$$V = dX/d\tau, \tag{4}$$

where m is the mass of CPS CR, kg; m_w is the added mass of water, kg; U is the acceleration of CPS CR, m/s^2; V is the velocity of CPS CR motion, m/s; τ is the current time, s.

The movement equation (1) represents a balance of the forces acting upon the CPS CR during its drop and damping. The hydraulics equation (2) represents a balance of pressure differential on the channel sections (refer to calculation procedure in Figure 1). Equations (1) - (4) are supplemented by the constitutive equations for calculation of the forces acting upon the CPS CR and for calculation of the hydraulic and mechanical resistance in the CPS CR channel. Accelerations in equations (1) - (4) and subsequent constitutive equations of forces, pressure differentials, velocities of displacement have a plus sign if the vectors of physical values are directed from above downwards and a minus sign at a direction from below upwards. In the left part of equation (1) the inertia forces of the dropping CPS CRs are determined with account for the CPS CR falling part mass "m" (CPS CR mass and extension shaft mass) and the added mass of water "m_w". Added mass of water includes the water contained within the blind cavities of the dropping system and the mass in volume of water to be displaced by the dropping CPS CRs [4].

In the right part of equation (1) the forces acting upon the CPS CR in case of drop and damping are determined by the ratios:

- gravity force F_w of the CPS CR falling parts minus the "Archimedian" force:

$$F_w = m\cdot g\cdot(1 - \rho_w(\tau)/\rho_m), \tag{5}$$

where g is the free-fall acceleration, m/s^2; ρ_w is the density of water, kg/m^3; ρ_m is the density of metal, kg/m^3.

- mechanical friction force F_{Fr} in the CPS CR channel (in FA, in protective tube unit (PTU) tubes and in ShEM drive):

$$F_{Fr} = f_{Fr}(X)\cdot K_2\cdot K_1, \tag{6}$$

where $f_{Fr}(X)$ is the tabulated value of the mechanical friction forces as a function of position coordinates X along the CPS CR height; K_1 is the coefficient introduced for possible consideration of influence of the CPS CR drop velocity and the water velocity in a gap upon the mechanical friction force; K_2 is the coefficient determining a direction of the friction forces with account for direction of CPS CR motion velocity V.

The coefficients K_2 and K_1 are calculated as follows:

$$K_2 = -1 \quad \text{at } \overline{V} \geq 0;$$

$$K_2 = 1 \quad \text{at } \overline{V} < 0;$$

$$K_1 = a_o + w_o \cdot (W_{G.b} - V)^2, \tag{7}$$

where a_o, w_o are the corrective factors;

- force of damper springs $F_{Sp}(X)$ (from the moment of CPS AR cap contact with the damper device till the FA cap spring coils are linked up);
- force of hydraulic impact upon the drive extension shaft $F_{E.s}$:

1) due to pressure differential occurred when the extension shaft moves out of the drive cavity during free fall:

$$F_{E.s} = -a_{E.s}(X) \cdot V \cdot |V| \tag{8}$$

2) due to pressure differential on the extension shaft occurred in case of housing rupture or main coolant pipeline (MCP) break:

$$F_{E.s} = -w_{E.s} \cdot \Delta P_{E.s}(\tau), \tag{9}$$

where $a_{E.s}(X)$ is the coefficient of proportionality between a value of hydraulic force acting upon the extension shaft and a square of velocity of extension shaft motion.

The coefficient $a_{E.s}$ is calculated according to the following formula:

$$a_{E.s} = \xi_{E.s} / 2 \cdot \rho_w(\tau) \cdot (S_{E.s} / S^{E.s}_{G.b})^2, \tag{10}$$

where $S_{E.s} = w_{E.s}$ is the coefficient of proportionality between the hydraulic forces on extension shaft and the pressure differential on extension shaft in case of drive housing rupture or MCP break; $S_{E.s}$ is the cross-section area of the drive extension shaft, m^2; $S^{E.s}_{G.b}$ is the flow area of the gaps; $\xi_{E.s}$ is the pressure loss coefficient (PLC) of gaps near the extension shaft; $\Delta P_{E.s}$ (τ) is the pressure differential on the extension shaft as a function of time under accident conditions with drive housing rupture or MCP break;

- hydraulic impact forces $F_{A.r}$ on the CPS AR section to be submerged into the guiding channels are determined as a sum of forces acting upon the absorbing element edge cross-section F_1 and upon the absorbing element lateral surfaces F_2:

$$F_{A.r} = F_1 + F_2 = \Delta P_{A.r} \cdot S_{A.r} + \Delta P_{A.r} \cdot S_{G.b} \cdot \chi, \tag{11}$$

where χ is the coefficient characterizing a fraction of pressure differential on the CPS AR lateral surfaces from a general pressure differential in the gap with account for differences in the gap water velocities with respect to wall of the falling absorbing element and with respect to a stationary wall of the guiding channel, and also with account for the absorbing elements and guiding channel perimeters (diameters).

The coefficient χ is calculated as follows:

$$\chi = z_1 / (z_1 + z_2); \tag{12}$$

$$z_1 = [y_1 + y_2 \cdot |W_{G.b} - V| \cdot (W_{G.b} - V)] \cdot d_{A.r}; \tag{13}$$

$$z_2 = (y_1 + y_2 \cdot |W_{G.b}| \cdot W_{G.b}) \cdot d_{G.c}, \tag{14}$$

where y_1 and y_2 are the corrective factors;

- pressure differentials on the guiding channel inlet section ΔP_{In} and on the CPS CR submerged section $\Delta P_{A.r}$ are determined by equations (15), (16) respectively, which include pressure differentials in the guiding channel on a section without absorbing elements and on the absorbing element submerged section (the first items in the equations (15), (16), and also the inertial components of water columns in the guiding channel on a section without absorbing elements and on a gap section between the absorbing elements and the guiding channel (the second items in the equations (15), (16)):

$$\Delta P_{In} = a_{In} \cdot |W_{In}| \cdot W_{In} + (H_{G.c} - H_o - X) \cdot \rho_w(\tau) \cdot (W_{In\,i} - W_{In\,i-i})/d\tau\,; \quad (15)$$

$$\Delta P_{A.r} = a_{A.r} \cdot [\chi \cdot |W_{G.b} - V| \cdot (W_{G.b} - V) + (1 - \chi) \cdot |W_{G.b}| \cdot W_{G.b}] + (H_o + X) \cdot \rho_w(\tau) \cdot (W_{G.b\,i} - W_{G.b\,i-i})/d\tau, \quad (16)$$

where a_{In} and $a_{A.r}$ are the coefficients of proportionality for pressure differentials included into the first items of the equations (15) and (16).

The coefficients a_{In} and $a_{A.r}$ are calculated as follows:

$$a_{In} = [\xi_{In} + (H_{G.c} - H_o - X) \cdot \lambda_{Fr}^{G.c} / d_{G.c}] \cdot \rho_w(\tau)/2; \quad (17)$$

$$a_{A.r} = [\xi_{A.r} + (H_o + X) \cdot \lambda_{Fr}^{G.b} / (d_{G.c} - d_{A.r})] \cdot \rho_w(\tau)/2, \quad (18)$$

where ξ_{In} is the resistance coefficient in the guiding channel tip (there are the lateral and central throttle holes in the guiding channel tip).

The resistance coefficient ξ_{In} is calculated according to one of the following formulae:

when the coolant flow moves from below upwards

$$\xi_{In} = a_1 \cdot (S_{G.c} / S_{l.h})^2 + w_1 \cdot (S_{G.c} / S_{C.h})^2 + c_1 \cdot (1 - S)^n \cdot (S_{G.c} / S_o)^2; \quad (19)$$

when the coolant flow moves from above downwards

$$\xi_{\mathrm{In}} = a_2 \cdot (S_{G.c} / S_{l.h})^2 + w_2 \cdot (S_{G.c} / S_{C.h})^2 + c_2 \cdot (1 - S)^n \cdot (S_{G.c} / S_o)^2, \quad (20)$$

where a_1, w_1, c_1, a_2, w_2, c_2 are the coefficients obtained on the basis of processing of the experimental data; $S_{l.h}$, $S_{C.h}$ are the flow areas of the lateral and central holes, respectively, in the guiding channel tip.

Values of S, S_o and n in formulae (19) and (20) versus the ratio of flow areas of the lateral and central holes in the guiding channel tip are assumed to be equal to:

if $S_{l.h} < S_{C.h}$

$$S = S_{l.h} / S_{C.h};\ S_o = S_{l.h};\ n = 1 \text{ at } W_{In} \geq 0;$$

$$n = 2 \text{ at } W_{In} < 0; \quad (21)$$

if $S_{l.h} > S_{C.h}$

$$S = S_{C.h} / S_{l.h};\ S_o = S_{C.h};\ n = 1 \text{ at } W_{In} < 0;$$

$$n = 2 \text{ at } W_{In} \geq 0, \quad (22)$$

where $\xi_{A.r}$ is the coefficient of resistance on the section of gap between the absorbing element and the guiding channel.

The coefficients of hydraulic friction $\lambda_{Fr}^{G.c}$ and $\lambda_{Fr}^{G.b}$ in equations (17) and (18) are determined by the ratios:

$$\lambda_{Fr}^{G.c} = \mathrm{W}_{G.c} \cdot \mathrm{Re}_{G.c}^{-\beta\,G.c}; \quad (23)$$

$$\lambda_{Fr}^{G.b} = \mathrm{W}_{G.b} \cdot \mathrm{Re}_{G.b}^{-\beta\,G.b}, \quad (24)$$

where $W_{G.c}$, $\beta_{G.c}$, $W_{G.b}$, $\beta_{G.b}$ are constants determined on the basis of the experimental data.

Reynolds numbers are calculated according to one of the following formulae:

$$\mathrm{Re}_{G.c} = |W_{In}| \cdot d_{G.c} / \nu; \tag{25}$$

$$\mathrm{Re}_{G.b} = \left| W_{G.b} - V/2 \right| \cdot (d_{G.c} - d_{A.r}) / \nu. \tag{26}$$

- velocity of water on the guiding channel inlet section, in the gap between absorbing elements and guiding channel and velocity of CPS AR displacement are mutually connected by the equation of continuity:

$$S_{G.c} \cdot W_{In} = S_{A.r} \cdot V + S_{G.b} \cdot W_{G.b}\,. \tag{27}$$

The current overloads experienced by the CPS CRs during drop and damping are determined by the equation:

$$A_g = 1 - U / g\,. \tag{28}$$

The ratios for the determination of PLC of the guiding channel tips, and also for determination of coefficients of hydraulic friction in the guiding channel tube and in the gap between absorbing elements and guiding channel as used in the calculation procedure and computer code are developed on the basis of experimental data about hydraulic spillage of these components [4].

When solving the equations to define the CPS CR dynamic characteristics [1], we use the Newton iterative method with division of the iteration step half-and-half in order to provide required stability of solution.

For zero time moment, the static calculation of CPS CR characteristics is performed that results in determination of the forces acting upon the CPS CR and of water velocities in the CPS CR guiding channel in the initial state.

Making use of initial approximation as regards water velocity in the gap between absorbing elements and guiding channel the specified value of water velocity in the gap $\overline{W}_{G.b\,o}$ is determined by the equation of hydraulics (2) using the Newton iterative method. Besides, by the equations (15), (16) the pressure differentials on the guiding channel inlet section $\Delta P_{In\,o}$ and on the absorber rod section $\Delta P_{A.r\,o}$ are determined.

For each subsequent iteration $\overline{W}^{\,p+1}{}_{G.b\,o}$ the following is determined by the Newton method:

$$\overline{W}^{\,p+1}{}_{G.b\,o} = \overline{W}^{\,p}{}_{G.b\,o} + \Delta W; \tag{29}$$

$$\Delta W = [\Delta P_{a\,z\,o} - (\Delta P_{In\,o} + \Delta P_{ps\,o})] \cdot dW / [(\Delta P'_{In\,o} + \Delta P'_{A.r\,o}) - (\Delta P_{In\,o} + \Delta P_{A.r\,o})], \tag{30}$$

where $\Delta P_{In\,o}$ and $\Delta P_{A.r\,o}$ are the pressure differentials on the guiding channel inlet section and on the absorber rod section as calculated by $\overline{W}^{\,p}{}_{G.b\,o}$; $\Delta P'_{In\,o}$ and $\Delta P'_{A.r\,o}$ are the pressure differentials on the guiding channel inlet section and on the absorber rod section calculated by water velocity in the gap $\overline{W}^{\,p}{}_{G.b\,o} + dW$; p is the number of the iteration.

The iterations are ended when the below condition is met:

$$\left| \Delta P'_{In\,o} + \Delta P'_{A.r\,o} - \Delta P_{a\,z} \right| \le \delta_1, \tag{31}$$

where δ_1 is the assigned accuracy of convergence of differences in the iterations by $\overline{W}_{G.b\,o}$.

Further, dynamic calculation of the CPS CR characteristics is carried out. Using initial approximation by the CPS CR motion velocity, applying the Newton iterative method we can define the specified value $\overline{V}_i$ in the calculated time moment i. For this purpose, using initial approximation by water velocity in the gap we determine the specified value $\overline{W}_{G.b\,i}$ for the calculated time moment i by the Newton method. Afterwards, the value of CPS CR acceleration U_i is determined for the calculated time moment from the equation (1) to be solved together with (3) – (11).

Then, the final velocity V_i and the average velocity $\overline{V}_i$ and the current coordinate X_i of the CPS CR position for the calculated time moment i are determined by the following equations:

$$V_i = V_{i-1} + U_i \cdot d\tau; \tag{32}$$

$$\bar{V}_i = (V_i + V_{i-1}) / 2; \quad (33)$$

$$X_i = X_{i-1} + \bar{V}_i \cdot d\tau. \quad (34)$$

For each subsequent iteration $\bar{V}_i^{p+1}$ the following shall be determined by the Newton method:

$$\bar{V}_i^{p+1} = \bar{V}_i^{p} + \Delta V; \quad (35)$$

$$\Delta V = (\bar{V}_i^{p} - (V_{i-1} + U_i \cdot d\tau / 2)) / [(U'_i - U_i)\cdot d\tau / (2\cdot dV) - 1], \quad (36)$$

where U_i is CPS CR acceleration with respect to velocity $\bar{V}_i^{p}$; U'_i is CPS CR acceleration with respect to velocity $\bar{V}_i^{p} + dV$.

Iterations are ended when the below condition is met:

$$\left| V_{i-1} + U_i^{p+1} \cdot d\tau / 2 - \bar{V}_i^{p+1} \right| \leq \delta_2, \quad (37)$$

where δ_2 is the assigned accuracy of counting as per $\bar{V}_i$.

Then the values of X_i , V_i and Ag_i are displayed in the graphic form and the parameter values are recorded in accordance with instructions in the initial data into the MD (diskette) file in the tabulated form [4].

Initial approximation for $\bar{V}_i$ and $\bar{W}_{G.b\ i}$ for the first time step $\tau_1 = \tau_o + d\tau$ are the values obtained as a result of static calculation and for each subsequent time moment $\tau_i = \tau_{i-1} + d\tau$ the values of V_{i-1}, $\bar{W}_{G.b\ i-1}$ are used based on those obtained in the previous time moment τ_{i-1}.

Cycle as regards water velocity in the gap between absorbing element and guiding channel $\bar{W}_{G.b\ i}$ is internal one as regards the cycle as per CPS CR velocity $\bar{V}_i$.

Criterion of convergence of the calculated values at iterations is fixed in the code and amounts to 0.01 % by the CPS CR velocity and 0.001% by the core pressure differential when solving the equation of hydraulics [4].

5. Analysis of the code's features

5.1. List of the input and output data

The initial data for calculation using the code [4] are:

- mass of the dropping system (of the extension shaft engaged with the absorber rod);
- added mass of water;
- geometrical parameters of absorber rods and guiding channel;
- average density of the CPS CR structural materials, coolant density and kinematic ductility;
- mechanical friction forces in the guiding channel;
- elastic forces of the damper device springs;
- coefficients of proportionality between a value of the hydraulic force acting upon the drive extension shaft, and a square of extension shaft velocity versus the CPS CR position along the height;
- value of the core pressure differential, value of the extension shaft pressure differential and coolant density as a function of time for non-stationary operating conditions of reactor;
- maximum physical time of CPS CR drop to be assigned for calculation;
- step of time increment separately on the dropping section and on the damping section.

For zero time moment the initial velocity equal to 0 and the initial coordinate of CPS CR position along the height are assigned to be counted from the core upper boundary. Coordinate of the CPS CR position equal to 0 corresponds to the CPS CR upper position [4].

As a result of calculation using the code the current time of CPS dropping and damping is determined as well as change in time of the following values:

- travelled way;
- displacement velocity;
- acceleration;
- current overloads acting upon the CPS CR during dropping and damping;
- forces acting upon the CPS CR during dropping and damping.

5.2. Substantiation of code operability

The code operability is confirmed during realization of design calculations of dynamic characteristics of the VVER-1000 CPS CR for various modifications of FA and CPS CR. These calculations have shown that the code is stable over the considered ranges of governing parameters such as the CPS CR and guiding channel geometrics, the operating, hydraulic and mechanical parameters (pressure differential on the core, temperature and pressure of water, mechanical friction force in the CPS CR channel) [4].

The code makes provision for a number of the control and diagnostic messages intended to inform the user, in particular, about mistakes in the initial data.

The results of code KLAST verification are submitted in [3]. Verification is made on the basis of experimental data obtained during tests of the ShEM drive, FA and CPS CR VVER-1000 reactor on the test rigs and under the real conditions at various nuclear power plant (NPP) Units.

For a set of the used experimental data obtained on the test rigs and being the most complete and precise, the root-mean-square deviation of calculation results from the measured values amounts to:

- by the CPS CR drop time – 7.6%;
- by the velocity of CPS CR approach to the FA cap – 13%.

The code provides accuracy of assessment of parameters during CPS CR dropping at reactor damage, mainly, as regards the mechanical friction forces in the CPS CR channels. When the mechanical friction forces do not exceed the design value of (49 N), the code provides assessment of the CPS CR dropping process during NOC and AOO with the above accuracy.

6. Conclusion

The calculation procedure, algorithm of calculation, technical characteristics of the code KLAST presented in the article confirm that the code KLAST allows to perform design calculations of dynamic characteristics of VVER-1000 control rods during CPS CR dropping and damping with regard to normal operating conditions and anticipated operational occurrences.

The code is applicable for calculations of dynamic characteristics of the VVER-1000 control rods under the design accident conditions with drive housing rupture and with pipeline break.

The code operability is confirmed during realization of design calculations of dynamic characteristics of the VVER-1000 CPS CR for various modifications of FA and CPS CR. These calculations have shown that the code is stable over the considered ranges of governing parameters such as the CPS CR and guiding channel geometrics, the operating, hydraulic and mechanical parameters (pressure differential on the core, temperature and pressure of water, mechanical friction force in the CPS CR channel). For a set of the used experimental data obtained on the test rigs and being the most complete and precise, the root-mean-square deviation of calculation results from the measured values amounts to: by the CPS CR drop time – 7.6%; by the velocity of CPS CR approach to the FA cap – 13%. The code provides accuracy of assessment of parameters during CPS CR dropping at reactor damage, mainly, as regards the mechanical friction forces in the CPS CR channels.

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Аналіз комп'ютерного коду і методики, що використовуються для тепло-гідравлічного обґрунтування безпеки реакторних установок типу ВВЕР

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Анотація

Дана стаття містить аналіз методики і комп’ютерного коду КЛАСТ, що використовується при розрахунках динамічних характеристик органів регулювання при обґрунтуванні безпеки водно-водяних енергетичних реакторних установок. Код дозволяє врахувати перепади тиску як функцію часу, що виникли в проектних умовах в активній зоні реактора та на валу приводу, а також зміну щільності теплоносія в активній зоні. Програма може бути використана для розрахунку динамічних характеристик органів регулювання системи управління і захисту реакторів типу ВВЕР-1000 в проектному аварійному режимі з розривом чохла приводу і для розрахунку динамічних характеристик органів регулювання системи управління і захисту в процесі падіння і демпфірування при спрацюванні автоматичного захисту в проектних аварійних режимах з розривом трубопроводів. В результаті розрахунку визначаються залежності динамічних характеристик органів регулювання системи управління і захисту від часу.

Ключові слова: реактор; теплогідравлічна безпека; розрахунок; динамічні характеристики; розрив трубопроводу; проектна аварія.