UDC 539.3:620.17:519.677.001.57(045)

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THE SYSTEM FOR POWER EQUIPMENT BREAK-DOWN SIMULATION

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This experience makes it possible to propose an automated system for simulating the nuclear and thermal power plants break-downs directly in the course of operation

Introduction

For providing of reliability and longevity of reactor and reactor room elements, the system, which provides prognostication of possible emergency situations, is needed. Nuclear plants, which were built nearly 30 years ago, had practically exhausted their reliability resource. Researches of present state of reactor elements constructions and development of the system, which will allow providing further safe exploitation, are needed. The principal scheme of atomic energy plant is given on fig 1.

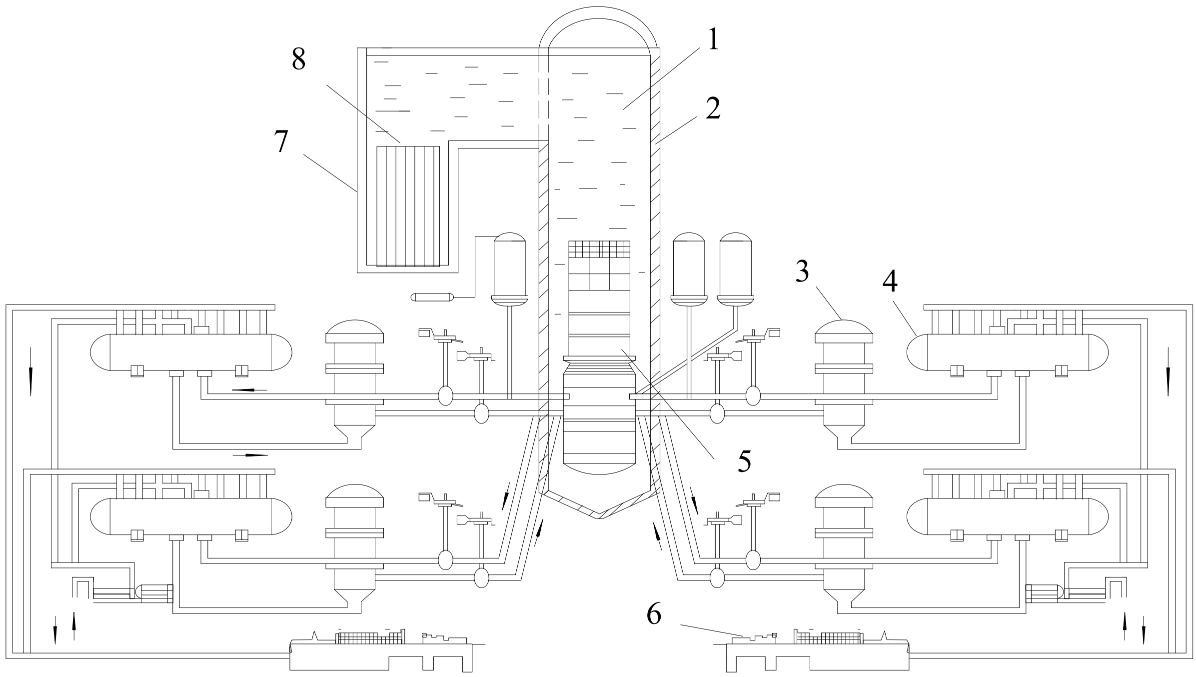

Fig. 1. Principal scheme of atomic energy plant:
1 – boron water; *2* – reactor shift; *3* – main circulation pump; *4* – steamgenerator; *5* – reactor; *6* – turbogenerator; *7* – endurance basin; *8* – shelves

Classification of reactor shaft coating failures

Failures classification, according to analysis results, made in work [1] in 89% of cases is connected with formation of cracks near welded joints and in points of joining of pipes and other elements.

We have come to conclusion, that welded joints and zones of thermal influence are the most probable places of damage of reactor shift coating because of existence of technological defects:

– which were not detected – 19%;
– corrosion-mechanical fatigue – 41%;
– mechanical or thermal fatigue – 29%;
– and others (including non-detected cases – 11%).

Defining of loads and influence on separate elements of a reactor shaft

Low cyclic loads (10^1–10^4 cycles) under action of big amplitudes of local mechanical and temperature deformations and strains are caused by start-ups and shutdowns of power plants, and emergency cases. These loads act on pipes, densing material, coating plates and welded joints of reactor shaft coating.

Multicyclic loadings, which can lead to multi cyclic fatigue of construction (10^4–$5x10^5$ cycles), are caused by pressure and temperature changes, at regulation of the equipment power (from 5 to 50%). These loads act on pipes, densing material between pipes and coating plates of the reactor shaft.

Long-term static loadings develop under high temperatures, when, during long-term work (10^3–10^5 cycles) in stationary regime under pressure and temperature, the creep deformations are observed. These loadings act on welded joints of reactor shaft coating.

Multicyclic fatigue loadings (10^7–10^{10}) are caused by action of vibration strains from mechanical fluctuations and hydrodynamical efforts, formed by flows of a heat carrier. These loadings are common for pipes, densing materials between these pipes and reactor shaft coating.

Thermocyclic loadings (10^3 – 10^4 cycles), are created by big differences of temperatures (473–723 K) in the cycle in welded joints of shaft coating in structurally non-homogenous materials.

Corrosion is caused by long term action of boron water on coating and welded joints of shaft coating.

Wear under contact and vibration interactions of pipes with each other and with shaft coating at densing material damages.

History of loading of a reactor shaft coating element

To determine durability, failure probability, material aging, fatigue damages accumulation and physical wear of any element of a reactor shaft coating it is necessary to construct a diagram of history of working parameters changes of reactor shaft loading (*P* and *T*) and history of studied element local characteristics changes σ, *T*, K_I, ε, as it is shown in fig. 2.

Rich theoretical and experimental experience has been accumulated in the world in the problems associated with the simulation of heat-mass transfer in power equipment, radiation and combined heat-mass transfer, thermal and radiation fatigue of alloys and composite materials used in reactors and power plants, as well as in the field of cyclic crack growth resistance and creep studies in elements of intricate shape used in power plants.

This experience makes it possible to propose an automated system for simulating the nuclear and thermal power plants break-downs directly in the course of operation.

The system of power equipment break-down simulation consists of "Measurement System", "Data Banks", "Functional Dependences System", "Simulation System".

The "Measurement System" is based on advanced complexes for measuring main parameters and characteristics describing the process of heat-mass transfer, changes in the service regime of power equipment, damage of the equipment material in the process of operation.

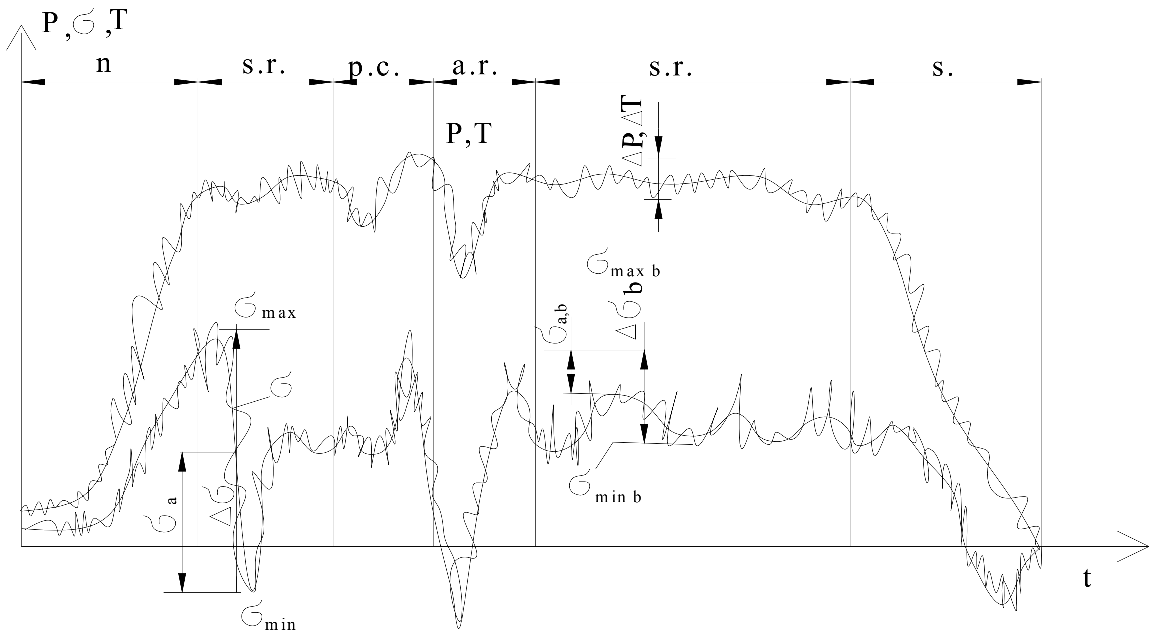

Fig. 2. The scheme of changes of working parameters and local strains σ during the exploitation cycle:
t – time; *P* – boron water pressure in the shaft; σ – strain in the given point of construction; *T* – boron water temperature.*s* – stop *n* – start; *s.r* – stationary regime; *p.c* – power change; *a.r* – accident regime; Δσ – strains difference; σ_a – strains amplitude; $\Delta\sigma_b$ – value of local strains; σ_{ab} – local strains amplitude

The signals from the measuring instruments are read out and stored in certain intervals of time and converted into the system of measuring the parameters to be determined. All the information is entered into the data banks which store the history of operation and changes occurring in power equipment.

The information stored in the data banks is subject to mathematical analysis and is converted into functional dependences which are the initial information for the "Simulation System" for power equipment break-downs. The break-down simulation system comprises a number of completely compatible program packages and the output data of any of them serve as the input data for the rest of the packages. Each of the program packages simulates only a certain type of changes, damages and break-downs.

During the operation of break-down simulation system a call to one or another program package occurs depending on the fact whether the assigned criteria are satisfied. The predictions of changes in characteristics, parameters and damages are stored in the prediction data banks. The system operates in accordance with the constantly changing algorithm depending on the fulfillment of the changes criteria.

The break-down simulation system operates until a certain break-down criterion is satisfied or until the prediction of occurring changes ceases or stabilizes with respect to all the parameters. Bellow one can find the description of the application program packages included into the "System", their functional application and brief characteristics. "Thermo" is the program package for solving the problems of stationary and non-stationary heat condition in linear and non-linear formulation for two-dimensional (plane and ax symmetrical) and three-dimensional bodies of arbitrary geometry. The boundary conditions of the problem can be of the first, second and third kind, as well as mixed boundary conditions. The finite element method is used as a numerical method. The finite elements are used in the shape of an arbitrary curvilinear parallelepiped with the approximation of temperature, geometry and thermo physical characteristics within the volume of the finite element in accordance with the linear, square and cubic laws or their combinations.

The main stages of the calculation process are: the collection of input information, typing of the data arrays of the finite element control characters field and the field of global unknown quantities with the purpose of subsequent control of the correctness of specifying them: reading-out of the temperature field of the previous time step and recording the temperature field on a magnetic medium at the initial instance of time: solving of the heat at conductivity problems: printing the fields in the form of tables.

"Fatigue" is the program package for solving the problems of fatigue and cyclic crack growth resistance for the two and three dimensional metallic structures of intricate shape. The program package involves the finite element method and allows to determine cyclic fatigue and thermal fatigue of power equipment elements of intricate shape with hollows, cracks or inclusions.

The program package "Fatigue" includes the following output parameters of the material damage accumulation:

– the magnitude of energy dissipated after the given number of thermal and mechanical load cycles;

– the parameters of anisotropy;

– the values of changed mechanical and thermo physical characteristics of the alloys after being subjected to thermal and mechanical loading according to the preset program;

– the magnitudes of residual stresses and strains in different directions and in different planes;

– percentage of one or another type of damage accumulated in the material;

– pediction of the number of cycles prior to damage of minivolume for the given thermal or mechanical loading regime.

The program package also includes the following output parameters of cyclic crack growth resistance:

– the magnitude of the crack opening displacement;

– the total magnitude of the dissipated energy necessary for the crack jump of the damaged zone magnitude;

– the dimensions of the damaged zone ahead of the crack;

– the crack growth direction;

– residual stresses and strains in the damaged zone ahead of the crack tip.

"Diagnostics" is the program package developed to obtain ultimate state equations (analytical expressions for the criteria) for structures of intricate geometry with combined heat-mass transfer subjected to radiation and non-linear deformation. In particular one can define analytical expression for the criteria of plastic flow in one or in two planes or gross plastic flow; the criteria of plastic flow stability; the criteria of the strain interrelation condition violation in the minivolume due to the shearing of planes; the criteria of crack growth onset at different points along the crack front; the criteria of the stable crack growth disturbance; the criteria of micro pore nucleation and of changes in the function of their accumulation, etc. The initial data for obtaining the equations of ultimate transitions are the equations obtained from the mathematical analysis of the functions which model experimental data using one of the parameters obtained on specimens for simple types of damage. "Bimetal" is the program package for determining thermodynamic state and damage accumulation in the region of a weld.

The program package allows to determine:
– non-stationary temperature distribution in a well for a specified welding practice and welded joint design;
– residual stresses in the weld and in the heat affected zone inducted in the process of non-stationary temperature variation;
– the size of admissible defects in a weld, heat affected zone, base metal for the preset character of thermal and mechanical loading of the weld and residual stresses calculated earlier;
– changes in thermo physical and physic mechanical characteristics of the metal in the heat affected zone;
– conditions of defects nucleation, their dimensions and orientation.

For the simulation of a non-linear stress-strain state in power equipment elements the break-down "Simulation System" comprises the following application program packages:
"Strength"– for solving the problems of thermal plasticity, strength and fracture mechanics of metallic structures of intricate shape;
"Polymer"– for determining the stress-strain state of polymeric structures (reinforced, cellular, sandwich-type ones, etc.);
"Concrete Structure"– for determining the stress state and strength analysis for concrete elements of nuclear reactors. "Shells and Membranes" – for determining the stress-strain state, frequencies and models of natural vibrations for thin walled shell structures in power plants. Value of strain σ in the given point of construction is determined by numerical method, MFE, for example (fig. 3).

Conclusion

This experience makes it possible to propose an automated system for simulating the nuclear and thermal power plants break-downs directly in the course of operation.

Literature

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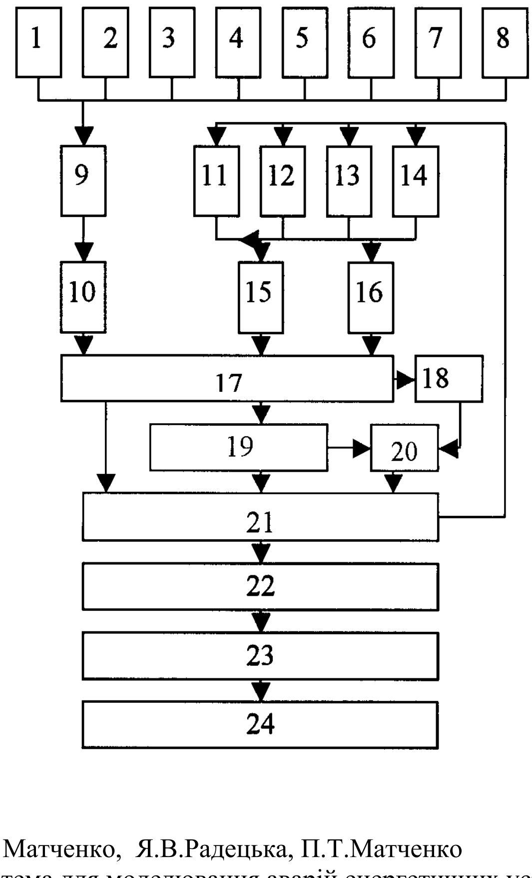

Fig. 3. The algorithm of residual resource determination of junction of steel with rigidity ribbing of black steel:
1 – junction geometry; *2* – limiting conditions of junction; *3* – mechanical characteristics of steels; *4* – chemical composition and concentration of aggressive medium; *5* – temperature regime of exploitation; *6* – mechanical regime of exploitation; *7* – radiation regime of exploitation; *8* – electrical regime of exploitation (stray current); *9* – model of a solid in the initial state; *10* – stress strain state of junction in the beginning of exploitation (t = 0, year); *11* – structural analysis of metal in the $t = n$ exploitation year; *12* – chemical analysis of metal in the $t = n$ exploitation year; *13* – geodetic measurements of junction location on $t = n$ exploitation year; *14* – experimental determination of cyclic cracks resistance limits; *15* – maps and probability models of spread: corrosion, erosion; pitting corrosion; intercrystalline corrosion; contact corrosion; crack corrosion; *16* – probability models of spread: multi cyclical fatigue resulting in the micro cracks development; low cyclical fatigue resulting in the cracks development; cyclical crack resistance; *17* – diagram of damage history in the $t=n$ exploitation year; *18* – changed mechanical characteristics of steel after inter crystal cracking; *19* – model of damaged junction in the $t=n$ exploitation year; *20* – stress strain state; *21* – kinetics of defects development in multifactor space; construction of the ω(durability) function; *22* – accumulated damages, integration of the ω function over time on all the defects in the $t=n$ year; *32* – residual resource determination; *24* – report on the construction state

The editors received the article on 10 May 2005.

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Система для моделювання аварій енергетичних установок

Запропоновано автоматизовану систему для моделювання аварій атомних і теплових енергетичних установок безпосередньо в процесі експлуатації обладнання.

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Система для моделирования аварий энергетических установок

Предложена автоматизированная система моделирования аварий атомных и тепловых энергетических установок непосредственно в процессе эксплуатации оборудования.