CALCULATED SUBSTANTIATION OF EMERGENCY COOLING SYSTEM DESIGN OPERABILITY FOR NUCLEAR POWER PLANT WITH A FAST NEUTRON REACTOR

Anatolii A. Nazarenko¹, Anton B. Korsakov²

¹Design Engineer, Dept. of Technological Calculations, JSC SPbAEP, Russia, St.-Petersburg (anatoly.nazarenko@gmail.com)
²Senior Engineer, Dept. of Technological Calculations, JSC SPbAEP, Russia, St.-Petersburg

ABSTRACT

It's not a secret that nuclear power plants face strict design, safety and exploitation requirements. Some of these requirements relate to withstanding the impact of the earthquake, blast wave and even aircraft crash, not to mention other emergency situations. For all these cases safety systems are being used and designed. Reactor emergency cooling system with air cooled heat exchanger (RECS ACHE) is one of them.

RECS ACHE (fig. 1) is an opened system with cooling air natural circulation. In cool down regime, air heated in ACHE, and having thus lower density in comparison with atmospheric air, rushes to the cooling tower outlet under the influence of buoyancy force, sucking cold air masses from the inlet. It steady-state regime buoyancy force is naturally balanced by resistance force of ACHE and air flow canal, i.e. with fixed height of the cooling tower and fixed level of the total heat release in ACHE, air flow through the system naturally sets at a level that provides the desired force balance. Thus RECS ACHE is a passive safety system.

Substantiation of system required detailed strength and flow calculations. Strength calculations were performed in accordance with Russian equipment and pipelines strength analysis norms for nuclear power plants PNAE G-7-002-86.

For flow calculations ANSYS CFX program was chosen. Velocity, temperature distribution, pressure loss, consumption rate versus heat release rate were analyzed.

For stress-deformed state calculation ANSYS finite element analysis program was chosen. Cold, steady-state, emergency regimes including external dynamic impacts (earthquake, blast wave, aircraft crash) were analyzed.

INTRODUCTION

For the considered RACS ACHE in emergency cooling mode from each of the two heat exchangers given value of heat capacity should be removed. For this purpose mass flow of air through each heat exchanger should remain at the desired level at the most unfavorable from the viewpoint of heat exchange outside air temperature of +40 °C. Then, for a given height of the exchanger (about 60 m) cooling air at the outlet of the heat exchanger will have a temperature that activates natural draft.

One of the main tasks of RACS ACHE modeling is to answer to the question of whether the system of a given height can provide required level of heat removal in the emergency cooling mode within the desired range of outdoor temperatures.

To answer this question the aerodynamic analysis of RACS ACHE performance was carried out using analytical techniques and with the use of a modern gas-dynamic calculation package CFX.

Not less important issue is the design strength of RACS ACHE under conditions of special dynamic external influences (seismic, airplane crash, blast wave). Since the proposed geometry of the structure is quite complex, the seismic analysis calculation is appropriate to carry out with the finite
element method, which allows reliably reflect the actual geometry. In this paper we present a finite element calculation carried out in the multi-package ANSYS with linear spectral method.

AERODYNAMIC ANALYSIS

Estimate calculations were made using hydraulic methodology for the flow path with a given nominal flow rate and fixed inlet and outlet temperatures of the cooling air. Calculations showed that the total value of the pressure losses in the inlet and outlet of RACS ACHE in conjunction with a given pressure drop in the air heat exchanger are on the level close to the amount of “useful draft”. That is, a conservative estimate [1] (with a choice of maximum efficiency of the flow path resistance) gives a value of 8.3% over the limit. A more optimistic assessment [1] (with the choice of the coefficients of local resistance by a different method), by contrast, gives the value of the total loss of 7% less than the “useful draft”.

In this situation, it seemed necessary to carry out additional clarifying research using numerical simulation of three-dimensional turbulent flow and heat transfer in the flow elements of the system. Such study would:

1. specify the value of the total pressure losses in the inlet and outlet of RACS ACHE in the current version of the design;
2. get a detailed picture of the flow, on the basis of which improvement of existing structures may be made;
3. clarify the useful draft by taking into account direct heat exchange of cooling air through the side surface of the vertical tube;
4. directly take into account the dependence of the coefficient of aerodynamic drag and heat transfer in ACHE from the flow of cooling air.

Numerical modeling of the flow in RACS ACHE means a numerical solution of the Reynolds averaged stationary Navier-Stokes equations for a compressible viscous fluid, closed with varying differential model of turbulence. The discretization equations are derived by the method of finite volumes using multi-block unstructured grid generation. Such calculations require high-performance multiprocessor computing systems developed by commercial software packages, such as ANSYS CFX and ANSYS Fluent. These calculations were carried out in the first of the listed packages.

RECS ACHE model with finite element mesh is shown in Fig. 1. The scheme of boundary conditions application is shown in Fig. 2. Wherein at the inlet is given mass flow, and the outlet remains "open". The model contains a surface of heat transfer of RECS ACHE with the environment, air flow shutdown system (AFSS) aerodynamic resistance and thermal power emitted from a heat exchanger tubes.

The analysis showed that the design of RACS ACHE meets the necessary requirements for air circulation to remove excess energy release.
Figure 1. RACS ACHE model with FE mesh.
Figure 2. Boundary conditions.
ANALYSIS OF THE STRENGTH UNDER CONDITIONS OF THE EXTERNAL DYNAMIC SPECIAL EFFECTS

Considered design attributed to I seismic category [2] and the possible dynamic effects for it are an earthquake, a plane crash and the blast wave.

The calculation was performed using the finite element method (FEM) in the software package ANSYS with shell finite elements. Total number of nodes in the model is 15469 (92814 degrees of freedom). A general view of the model is shown in Figure 3.

The response analysis of structures to seismic loads was performed using the linear-spectral method (LSM) based on the representation of the seismic action in the form of response spectra (RS) and the use of the principle of modal superposition [3,4]. With the help of RS maximum $R_i$ are determined as absolute values of the modal response (displacements, internal forces, stresses, reactions, etc.). These modal responses $R_i$ must be collected to obtain the total seismic response of $R$. Characteristic RS data envelope for considered system is shown in Figure 4.

After the calculations detailed stress strain state was obtained. To ensure construction strength necessary changes were included in the design.
CONCLUSION

As a result:

- Specified amount of the total pressure loss in the inlet and outlet of RACS ACHE in the current system.
- Produced a detailed picture of the air flow, judging by which there is no need to improve the design in terms of gas dynamics.
- Specified amount of useful draft through direct account of heat exchange cooling air from the side surface of the riser team.
- Evaluated the structural strength at possible dynamic effects and make the necessary changes to its performance.

REFERENCES

2. NP-031-01 "Standards of earthquake-resistant design of nuclear power plants"