UNDERSTANDING THE NECESSITY FOR INCLUSION OF NEW REQUIREMENTS TO EXISTING NPP REGULATORY DOCUMENTS AND INSTRUCTIONS

Proskuryakov K.N., Afshar E.
Moscow Power Engineering Institute (Technical University),
14, Krasnokazarmennaya str. 111250, Moscow, Russia.
Phone: +07 (495) 362-73-51, Fax: +07 (495) 362-73-51 e-mail: prosk@npp.mpei.ac.ru

1. Introduction

In the present time priority problems of Nuclear Power Plants (NPP) improving are: prolongation of lifetime, increase of an economic efficiency and safety. The detail researches on the factors determining the nature and level of dynamic loads on NPP equipments and reactor internals are required for solution of these problems [1, 2].

Resonant destruction of constructions takes place in cases when Eigen-Frequencies of Oscillations of the Coolant Pressure (EFOCP) begin to be equal to the eigen-frequencies of structural oscillations. The most dangerous dynamic interaction of the equipments and the fluid flow are supposed to be in the resonance region of mechanical oscillations of the elements and the parameters of the flow. To prevent the appearance of the conditions for resonance interaction between the fluid flow and the equipments, it is necessary to provide the different frequencies for the self oscillations in the separated elements of the circulating system and also in the parts of the system formed by the comprising of these elements. To solve these problems, it is necessary to develop Vibro-Accoustics Specifications (VAS) which describes the EFOCP and eigen-frequencies of structural oscillations in definite elements and in operational conditions. Thus, to provide the VAS of NPP, it is necessary to determine following parameters:

- frequencies of the self oscillations of the equipments, in the combined elements and their compositions in the different operating regimes of the reactor in the normal and accidental conditions,
- EFOCP in the combined elements and their compositions in the same operating conditions.

Based on the VAS of the NPP, the development of the methods and the tools for the prevention of the appearance of the conditions for resonance interaction between the equipments and the working fluid in the normal and accidental conditions could be done. To do this, in particular, it is necessary to prevent the overlapping of the peaks of the spectral characteristics of the signals obtained from the Transducers of the Pressure Pulsations (TPP) of the working fluid and the signals from the transducers of the vibrations, displacement, loads and etc. At present time, due to this fact that the VAS of the NPP is not a necessary part of the design and regulatory documents, it is not being done objectively [3]. To describe the reasons for this, it should be noted that there exist problems that could be solved by further development of the methods for modeling of oscillation processes in reactor power units. At present time, a lot of important results have been obtained in the field of modeling and calculations of spectrum oscillations of the constructive elements of the equipments [4]. However, there exists a hindering in the evolution of the methods for modeling and computations of the spectrum frequency oscillations for the working fluids, filling the construction elements and the equipments in general.

Next step is to create the computational models and methods that should take the complex formation of reactor loop coolant acoustic parameters into account, and also must be verified in operating NPP's. For this purpose the NPP should have the appropriate noise signal measuring system, modern diagnostic methods and devices and abnormalities identification possibilities using the equipment operating noise analysis, including neutron noises of reactor installation analysis.

The following step is the development of thermal hydraulic computer codes that include these above mentioned models. The fact, that modern codes and, accordingly, the models incorporated in them are far from perfect, it is marked by a number of authors [5]. The greatest discrepancy in values of flow rate and pressures predicted by codes to the data of experimental measurements is marked in area pulsating modes, i.e. in those modes when thermal hydraulic circuit shows itself as nonlinear oscillating system [2].

2. Thermal-hydraulic reasons of growth of dynamic loads and cracks in the NPP equipments

The basic researches that have been carried out in the Department of Nuclear Power Plants (DNPP) in Moscow Power Engineering Institute (Technical university) MPEI (TU), show, and also the current practice, confirms the presence of the unforeseen dynamic processes of resonance type in thermal hydraulic circuits with liquid or steam-gas-liquid working fluid which are not stipulated by the design documentation and not predicted by thermal hydraulic computer codes.

In many cases, this is the reason behind sudden failures and accidents in the equipments in NPP's and in other industrial units. In nuclear engineering, the control of integrity and stress conditions of Reactor Vessel Lid (RVL) of nuclear power reactors is one of the most important and urgent problems. To reduce the risk of severe accidents in NPP's , it is necessary to solve this problem. The incident in Davis – Besse -1 NPP (USA) in February 2002 in the USA [6], has shown the actuality of this problem.

Incident on the Davis-Besse-1 reactor unit was connected with non-integrity of RVL metal and has been categorized as the second most serious accident after Three-Mile-Island-2 in 1979. The expenses related to the replacement of RVL, and also including those due to the idle time of the NPP's, consist of hundreds of millions of dollars. Now the number of replaced RVL's in all countries is about 50 units.

The researches lead by MPEI (TU), are focused on creation of alternative solution of the problem related to prolongation of service life of RVL and reactor installations, in general. The possibility of such solution is provided by the application of developed methods and the means limiting the level of vibrations and the dynamic loads caused by them, i.e. capable to reduce the role of one of the factors causing the formation of cracks in RVL metal.

The results of the carried out analysis show, that in NPP's and in other industrial units, there are significant unused opportunities for service life increase of the equipments and reduction of probability of their sudden failures caused by thermal hydraulic reasons. The works conducted by NPPD of MPEI (TU) include the kind of works that have not been declared by other researchers and the organizations, containing the development of methods and means of forecasting and prevention of resonance interaction of liquid and gas-vapor-liquid medium fluctuations with equipment vibrations.

The tasks of the design of the acoustic models for the coolant and the equipments of NPP, for the separate equipments, main equipments, and for the whole components of the primary circuit have been first solved in [7]. The developed models and algorithms for calculation of EFOCP and the need for the possible changes of thermal-hydraulic parameters of the coolant make it possible to prohibit the resonance between EFOCP and the natural oscillations of Fuel Assemblies (FA), reactor internals and the main equipments of NPP. This inequality between the frequencies permits the increase of the resources and prolongs the service life of the NPP in general. To show this situation, we use experimental data that have been obtained from the measurements of noise signals in the frame of the cold -ops, hot -ops and nominal operation program done at for the first power unit of Volgodonsk NPP (Vo NPP) [8].

In Figure1, the Auto Power Spectral Densities (APSD) of vibro accelerations date obtained from the transducers installed on top reactor unit; in the zero power operation mode of reactor is given.

The outstanding characteristic for this spectrum is the dominant peak that correspond the frequency equal to three times of rotation frequency of the pump, which is equal to 49.8 Hz. Its value is some orders of magnitudes higher than the others, including the rotational frequency of the MCP equal 16.6 Hz. The understanding of this phenomenon is based on the analysis of the obtained results of the calculated values of EFOCP [8].

Figure 2 presents APSD of coolant pressure pulsations, show the dominant peak equal to three times of rotation frequency of the pump [8]. These oscillations would be strengthened only in the primary circuit in operating condition, when values of EFOCP of Reactor Core (RC) at operating condition are equal to 49.8 Hz.

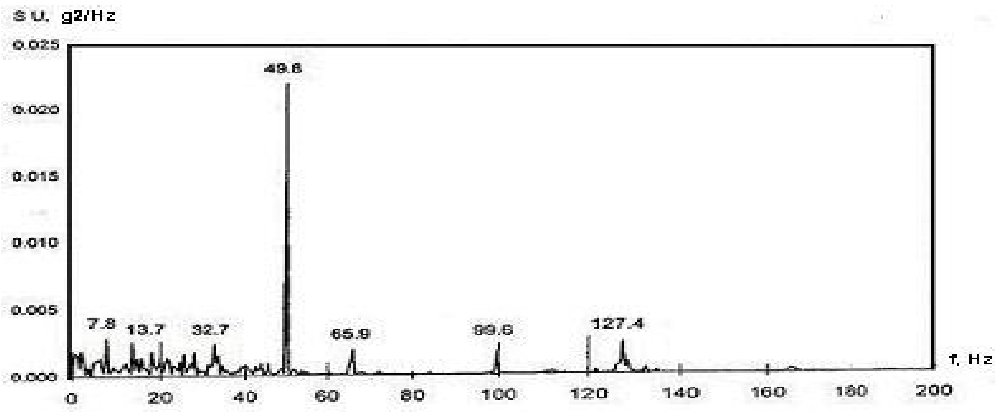

Figure 1 The spectrum of vibro acceleration. Transducer 02BI-1 (installed at top reactor unit). For working MCP 1,2,3,4, P=15.9 MPa, T=270℃.

One may reveal the reason for the increase of vibrations level in RVL at zero power condition by using the values of EFOCP from the [9]. The values of EFOCP of reactor core at zero power level are equal to 49.3 Hz, i.e. its value is practically equal to the frequency oscillations of coolant that is caused by the rotation of MCP and hence strengthens them. By the way the values of EFOCP of RC at nominal reactor operating condition is equal to 41.5 Hz, i.e. it's outside the range of mutual resonance of coolant pressure oscillations caused by the MCP rotations and the EFCPO RC. By decreasing the power level of reactor, the values of EFCPO RC would approach to the range of mutual resonance effects.

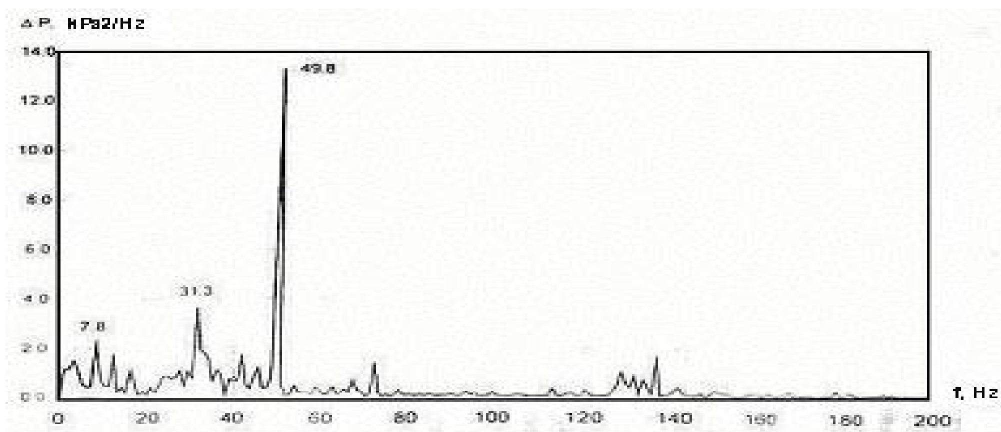

Figure 2 The spectrum of pressure pulsations from TPP BP-8 (reactor internals, reactor barrel, exit from loop No 4). For working MCP 1,2,3,4, P=15.9 MPa, T=270℃.

The analysis shows that the formation of defects in RVL of VVER-1000 reactors occurs at the most unfavorable operating condition of reactor at zero power level with pressure and temperature of coolant near to following values: P=15.9 MPa,, T=270^{0}C.
The problem was first noticed in Bugey-3 in France in 1991 [6] (Similar damages have been identified in other NPP's: Sendai-1 (Japan), Jose Cabrera-Zorita (Spain), Beznau 1 (Switzerland). At present time, the pre-matured dynamic fatigue factor in the materials of the RVL is not considered by experts as the one of the reasons for the destruction of RVL.

Investigations to find other reasons for this effect are limited by the corrosion influenced by acid boric.
The analysis given above shows that, at present time, one of the main reasons for the premature leakage of the pressure vessel heads of VVER-1000 and PWR reactors have not been revealed and yet removed by the designers. The problem could be solved on the base of development of NPP VAS. Worked out R&D [10] give understanding of the existence of the concealed dynamical loadings in thermal hydraulic circuits of NPP

caused by parametrical excitation of coolant pressure oscillations, which at present time, are can not foreseen in design and normative documents and not predicted by the thermal hydraulic computer codes. To show this phenomenon, we use experimental data which have been obtained in [8].
APSD of signals from the same TPP that is installed in core outlet are shown in Figures 3 and 4.

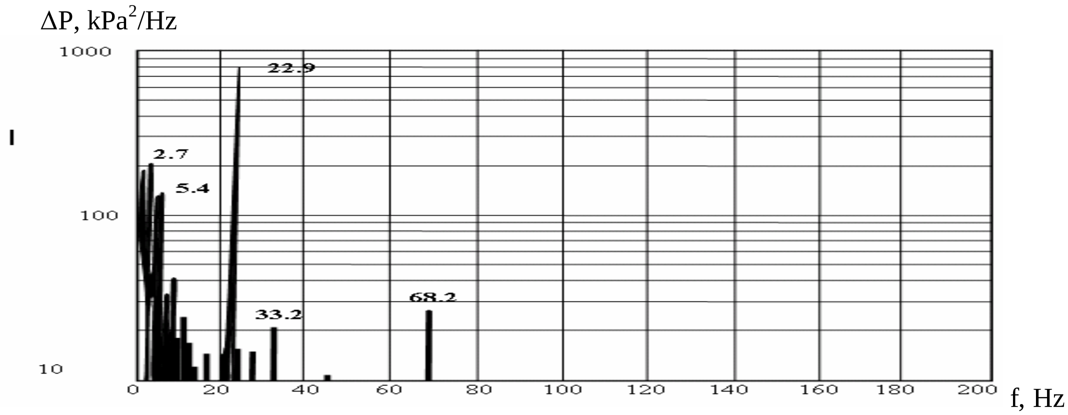

Figure 3 The APSD spectrum of pressure pulsations. TPP BP-11 (main pipelines, first loop, core outlet). For working MCP 1,2,4, P=16.0 MPa, T_{outlet} =314 ºC, T_{inletd}=285 °C.

As a result of the analysis, some laws of formation of measured signals APSD are revealed. By comparison of results, abnormal growth of intensity of pulsations of pressure in frequencies 2.7, 5.4 and 22.5 Hz. are found that are given in Figure 3, in comparison with their values resulted in Figure 4.

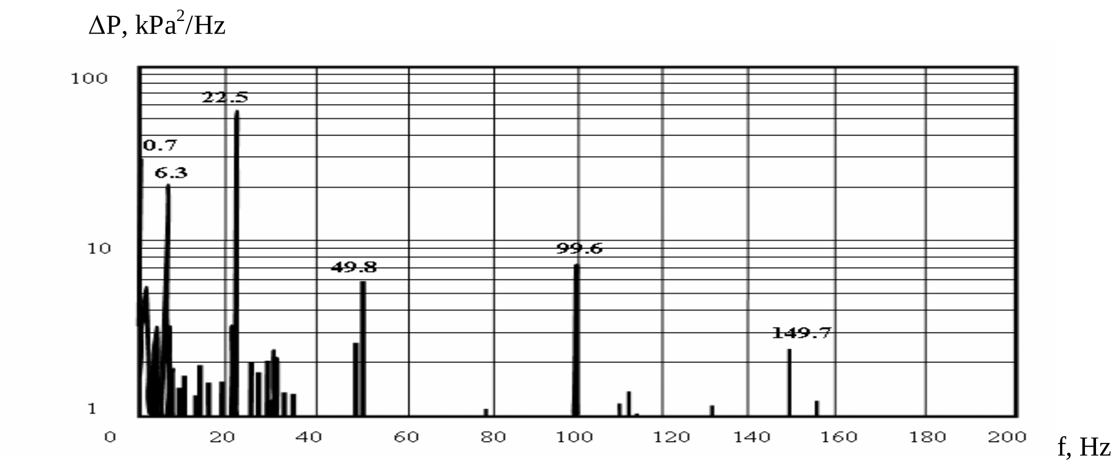

Figure 4 The APSD spectrum of pressure pulsations. TPP BP-11 (main pipelines, first loop, core outlet). For working MCP 1,2,3,4. P=16.0 MPa, T_{outlet}=318 ºC, T_{inletd}=287 °C.

To investigate about the reasons behind the appearance of abnormal high pressure pulsations, the assumption of occurrence of parametrical resonance in coolant pressure oscillations has been applied. Calculations have shown that at definite mass gas content in adjacent oscillatory coolant circuit's number 1 and 2, the EFOCP doubling ratio takes place. That is, the cooling circuit number 1 consists of reactor core and space above it that has EFOCP equal to 5.4 Hz, and the second circuit consists of steam generator hot collector and the pipeline connecting it to the reactor vessel that has EFOCP equal to 2.7 Hz. As shown in [10] excitation of a parametrical resonance occurs at the minimal value of its modulation as a result of doubling the change of acoustic capacity in the circuit. In this example, the variation of capacity in circuit number 1 is twice for one period of coolant self oscillations in circuit 2. The doubling EFOCP relation is observed only in a narrow range of changing operational parameters.

3. Perspectives for increasing the reliability and service life of the NPP equipments

Considering the research results of vibro-acoustic measurements which have been carried out in the commissioning stage of VVER-1000 NPP, it is possible to understand the reason of underestimation of the role of high-cycle loadings in occurrence of cracks in metal of the primary equipments of the first circuit.

The mode in which resonant interactions with the coolant takes place, can be designed and predicted on the basis of application of the developed methods. It concerns to reactors of PWR types, like Davis Besse, and to any type of reactors with water or steam-and-water coolants.

It is necessary to emphasize, that combinations of parameters for the reactor operating mode in the worst case for RVL, for each reactor will be unique. Generally, they are determined by considering the geometrical sizes of the reactor, RC, the equipment, pipelines, thermal hydraulic parameters of the coolant and the scheme of its movement.

Thus, as shown above, measurements and analysis results of operating parameters oscillation in a primary loop of NPP with VVER-1000 are adduced. Amplitudes increasing of coolant pressure oscillations in narrow range of operating parameters are revealed. Mathematical and experimental proof of phenomena of parametric excitation of oscillations in the fluid is presented. There is a necessity for advanced thermal- hydraulics computer codes to be capable to reveal the conditions of parametric excitation of coolant oscillations and resonance interaction between coolant and structures. And also there is a necessity for monitoring diagnostics and control tools to be able to prevent or limit the dynamical loadings stipulated by the same phenomena. The researches carried out, allow determining procedure for control of residual resource of RVL and other equipments and the timely warning to the personnel about reaching of maximum permissible level of dynamic fatigue of metal.

These requirements will consist in development of the detailed monitoring and accumulation of the measurement results of coolant oscillations, mechanical vibrations and dynamic loads in the vicinity of expected mechanical and hydro-dynamical resonances and in their mutual resonant interaction.

Results of monitoring and calculation forecasting of beginning of resonant modes could be a basis for improvement of existing operating instructions

4. Conclusions

The worked out R&D provides the understanding of the nature of the concealed dynamical processes in thermal hydraulic circuits of NPP, which are not be foreseen in design and normative documents and not predicted by the thermal hydraulic computer codes.

The basis research shows, that these processes appear in the form of self oscillations, caused by the equipments and coolant resonant interaction and other system effects. In many cases, due to the existence of these physical phenomena and processes, sudden failures of the equipments and accidents occur.

To enhance the reliability and safety and lifetime of NPP, it is necessary to develop the VAS of NPP. VAS of the equipments and coolants are the important challenging problems, their solution is possible in the case of common use of the results from the basis research and the current operation experiences.

The obtained results and the results of analysis show, that in NPP's, there are significant unused opportunities for increasing the reliability and service life of the equipments, and also reduction of probability of occurrence of sudden failures and risk of the accidents caused by thermal hydraulic reasons.

These worked out results show the necessity for inclusion of new requirements to the existing regulatory documents and operation instructions for NPP's

5. References

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As required by regulatory documents, this list is a list of deviations from the effective Nuclear Safety Standards and Rules as compiled based on results of the NPP unit safety analysis (PSAR, RD nonconformity analyses). The said list is not published.Â with the necessity for establishing radioactive waste disposal points, and for effective RW. handling activities and equipment); - abandonment of generation II NPP units using the Â«immediate disassemblyÂ» option. The cost of decommissioning and handling of the spent nuclear fuel remaining at units.Â - Rostechnadzor has regulatory documents that contain detailed requirements and. instructions with respect to the contents of the emergency response plans for all types of. nuclear installations Existing regulatory documents for NPP I&C systems are tailored to meet for pre-FPGA technologiesâ€™ requirements and limitations. Additionally, a number of existing regulatory documents address safety issues related to software applications running on standard platforms, such as personal computers or embedded hardware platforms. Given the FPGAâ€™s dual nature, being both hardware and software, and its inherent complexity, there is a need for a FPGA-specific regulatory documents that would address issues, such as system safety assessment, design life cycle, verification and validation, configuratio... The New Payments Platform (NPP), launched in February 2018, is a fast retail payments system developed by a consortium of 13 financial institutions, including the Reserve Bank. The NPP provides the clearing and settlement infrastructure through which financial institutions can provide their household, business and government customers with the ability to make fast, versatile and data-rich payments on a 24/7 basis. Utilising the Fast Settlement Service (FSS) provided by the Reserve Bank, payments through the NPP are settled between financial institutions in real-time, which enables financial in... This document establishes design requirements and expectations for new NPPs. It also includes high-level requirements and expectations related to DECs.Â The NPP's safety assessments have confirmed that increased safety is achieved. The CNSC Regulatory Framework has been updated to include appropriate requirements and guidance related to design, analysis and operation of NPPs. Several of these activities are still ongoing. This document describes a consistent approach to establishing requirements and guidance related to DECs and although the paper presents a series of questions for the reader's consideration, comments and feedback should not be limited to these. Comments on any issue pertinent to the topic of DECs are encouraged.