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Dynamical Analysis at ŠKODA JS a.s.

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ABSTRACT

Design Analysis Department, ŠKODA JS a.s., provides calculations in the fields of stress and dynamical analyses, lifetime analysis of structures, physical calculations of nuclear devices, calculations on radiation safety, and on thermo-hydraulics. This contribution describes certain calculations of mechanical structures that were performed in the course of last three years.

KEY WORDS: dynamical analysis**,** stress analysis**,** thermohydraulic calculations, lifetime analysis, calculation models, computational methods, and finite element method.

HYDROGEN RECOMBINER

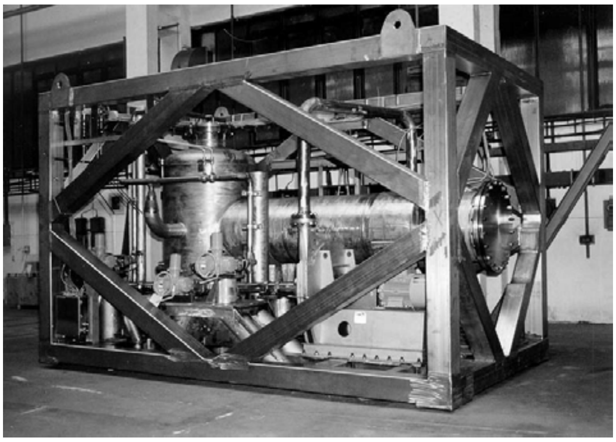

Fig. 1. View of the recombiner mechanical part

The recombiner was designed in ŠKODA JS a.s. in cooperation with the SIEMENS company. Once the recombiner development had been finished, four pieces were produced and delivered to the nuclear power plant Lungmen, Taiwan. The company GE Nuclear Energy was overall supplier of the plant.

The hydrogen recombiner is a device, which keeps the hydrogen concentration within the containment below 4 per cent. Hydrogen generation occurs in reactor emergency operation conditions, for instance at LOCA. If the hydrogen concentration exceeds an established limit, the hydrogen recombiners ensure oxygen-hydrogen mixture combustion thus maintaining the hydrogen concentration on safe level.

Fig. 1 represents the recombiner's main mechanical part, which was the structure we were in our computations about.

Fig. 2. offers two views of one calculation model of this part of hydrogen recombiner. It is composed of reaction chamber, which leads to a vertical water spray cooler and blower, and of three robust closing valves. All these parts are interconnected with corresponding pipelines and completed with measuring elements (thermocouples and measurements of levels, flows, and pressures). They are attached to the bottom side of the skid and then to the steel plate, which forms the top surface of the foundation from reinforced concrete.

Temperature, stress, and dynamical analyses of the main working part of the recombiner were performed. The calculational models were modified following the type of the problem. A great attention was given to the design and computations of anchoring because it must satisfy even the greatest considered earthquake (SSE), after which the plant would be shut down.

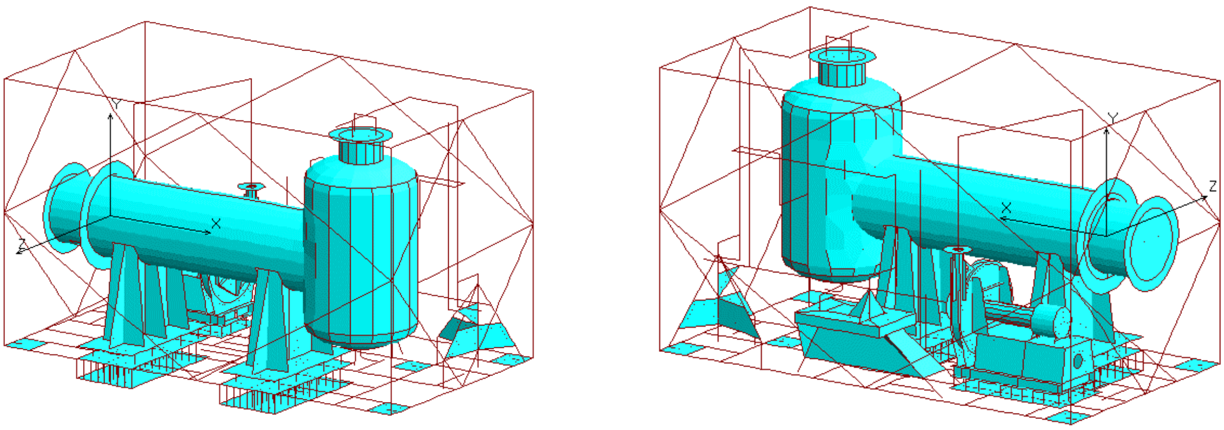

Fig. 2 One of the calculational models of hydrogen recombiner

Three conditions were defined for thermohydraulical analysis of reaction chamber with cooler. They are the nominal service condition typical for routine operation and two emergency conditions. The first emergency condition assumes that the temperature within the nuclear reactor containment would increase to 170°C, the input pipe fitting incidentally opens, and the recombiner gets abruptly filled with hot gas. The other assumes cooling water supply break while the recombiner is in operation. This break would cause temperature increase inside the cooler up to 720°C.

The computation of temperature distribution within the nominally operated recombiner structure was seen as a stationary problem when there have been specified approximate temperatures inside the reaction chamber, ambient air temperature, and conductivity and heat transfer coefficients. This calculation yields temperature distribution in particular parts of the reaction chamber and cooler. Subsequent stress analysis gives the stress due to heat tension. We have found that the maximum conventional stress (142 MPa) in nominal operation condition is in the weld between reaction chamber and cooler. This location shows maximum temperature gradient because it finds itself near the reaction chamber where the temperature on the inner surface reaches as much as 890°C. On the opposite side is the cooler with temperature of about 100°C. Moreover, this place is poorly shaped. One of the terms set forth by the customer requires that the temperature on the recombiner jacket surface, which is a pressure interface, might not exceed 250°C. The temperature on the outside surface of insulation may not exceed 60°C. Our analysis checked even these requirements.

Two specified emergency conditions were solved as non-stationary heat conduction problems. Data on time step and calculation duration were added to other specified data similarly to the analysis of nominal service condition. Not only temperature distribution but also the stress state was evaluated as time-dependent for these service conditions.

The first emergency condition exhibited maximum conventional stress (81.3 MPa) at the attachment of the cooler inner jacket to the outer jacket. As for the other emergency condition, we have obtained maximum conventional stress at the same location. Here however is the value substantially higher (462 MPa).

Stress analysis. In addition to the stress state analysis mentioned in the previous paragraph caused by the temperature distribution we also calculated the stress state of the recombiner structure loaded by its dead weight and internal overpressure. The same calculation model as for the temperature distribution and corresponding stress state computation was used in both these analyses.

Dead weight induces only very little stress state in the structure. Peak of the conventional stress after Tresca is 10.3 MPa.

Calculation of loading due to internal overpressure was based on the design pressure of 0.31 MPa. This loading is very little too and the peak stress lies in the weld between the reaction chamber and cooler (47.6 MPa).

Dynamical analysis was performed in two phases. First, we used a simplified calculation model. We investigated the effects of specified building vibrations for specified combinations of emergency conditions. This excitation was given in the form of horizontal and vertical response spectra. Furthermore, combinations of loadings for levels A to D in the sense of the standard [2] were specified. These combinations were given for linear type support components and for pipelines. Fig. 3 is an example of given floor response spectra for floor elevation of 12.3 m, damping 2% and for their combination of level B.

The first step of dynamical computations involved calculation of sufficient number of natural frequencies. Fig. 3 suggests that the floor response spectra were defined in the range from 0 to 100 Hz. However, the constant values of excitation above 60 Hz are very little. We used therefore only first 15 natural frequencies from the range from 0 to 60 Hz in the first phase. One of the significant normal modes of vibration, when predominantly the reaction chamber with cooler is vibrating on the supports, is depicted in Fig.4.

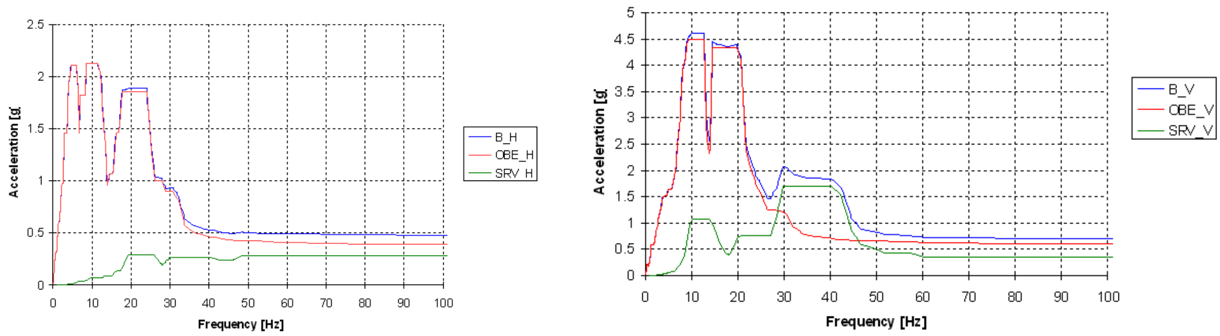

Fig. 3. Example of combination of floor response spectrum for level B, damping 2%

The results of the computation for various loadings obtained by means of the simplified calculation model were used for dimensioning the anchor bolts and revising the saddles. Level A prescribes only dead weight and temperature as a combination for loading the supports. Since we have chosen such design approach, which practically excludes that the supports be loaded by enhanced temperature, we only have to consider the loading due to dead weight, which had already been in use in the static stress analysis.

The combination required by level B consists primarily of loadings due to dead weight and temperature. Next, the SRSS method is used to add together the loadings due to OBE (Operating Basis Earthquake) excitation and due to spectra excitation, which occurs after opening safety valves. Both are then superposed.

The combination required by level C is entirely the same; only the so-called “chugging load” substitutes the OBE excitation.

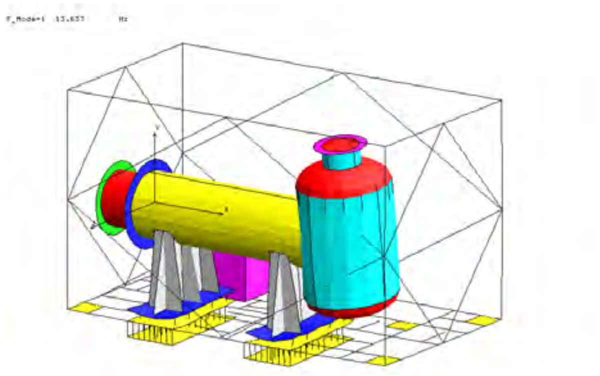

Fig.. 4. Recombiner first normal mode of vibration

Another two rules for the level D, which we have denoted as Da and Db, have been defined by analogy. Here the OBE excitation is substituted by greater values of response spectra for earthquake SSE (Safe Shutdown Earthquake), in which the nuclear plant gets shut down. With the level Da, this excitation means that the response spectra for chugging load and spectra due to opening of the safety valves (Safety/Relief Basement Acceleration Loads) geometrically add. If the level Db is the case, the spectra for the chugging load are substituted by the spectra that the customer calls condensation oscillation.

In [1], the customer has specified the coefficients for multiplying the values of allowable stresses listed in the Standard [2], Section II for each of the five levels. The values obtained in this fashion are then compared with the conventional stresses after Tresca theory. In such a manner, the anchor bolts, supports, and reaction chamber and water spray cooler bodies were dimensioned.

The other phase was focused on valve supports analysis. For this purpose, we have used a complete calculation model supplemented with vented piping and valve supports design. This model distinguishes for better modeling of the blower (see Fig. 1). Again, the first step was to calculate sufficient number of natural frequencies. To achieve higher accuracy, we have determined 50 lowest natural frequencies in this case thus covering the whole range of specified response spectra. The maximum natural frequency that we have determined is 101.6 Hz. Furthermore, we generated nine time-dependent acceleration functions corresponding to nine given curves of response spectra for any excitation (acceleration versus frequency function). Their combinations yielded functions for four levels, namely B, C, Da, Db. We have used these functions for exciting the recombiner nodes connected with the basement. Then, considering the nodes in the valves centers of gravity, we have determined response spectra, which we compared with given curves. If the spectra overlap the given curves, the design of valve supports was being modified as long as a satisfactory solution was reached.

The same approach was applied with pressure transducers.

In addition to the previously mentioned calculations, a whole series of standard calculations according to [2] was necessary to carry out in the course of recombiner design development. Concerned are pressure vessels, their flanges, supports, pipes, and recombiner components. Further, we co-operated in preparing suitable arrangement of insulation. We also generated response spectra at heating elements attachment. The spectra were then used for testing their seismic resistance in the testing laboratory in Erlangen, Germany.

STUD TENSIONER

Another equipment that was developed and manufactured in ŠKODA JS a.s. is stud tensioner of pressure vessel main flange joint of nuclear reactor in Lungmen, Taiwan. Detailed description of calculations made for this order will be presented in an individual paper.

VIBRATION OF SUPPORT CYLINDER VVER 1000

Pressure pulsations in the room between the pressure vessel and support cylinder as well as the support cylinder vibrations were measured in the framework of dynamical measurements performed during the final testing of nuclear reactor 1000 MW in Temelín. Support cylinder vibrations were somewhat higher than the design documentation had expected. On this ground, we proceeded to the calculation of support cylinder vibrations due to pressure pulsations and to the calculation of corresponding stress state and subsequently, to evaluating the influence of this stress state on the support cylinder lifetime.

Geometrical model was created by the program I-DEAS. The body of the support cylinder is an axi-symmetric, almost cylindrical shell with half-elliptical bottom. Solid bottom with adequately weakened thickness replaces the holed-bottom (163×∅50 mm and 1344×∅40 mm). The shell thickness varies with the height of the cylinder (Fig. 5). To be able to specify the pressure pulsations, we have modeled circular surfaces opposite the nozzles of primary circuit.

With this geometrical model, we have compared 30 natural frequencies for various types of elements. After having had achieved sufficient agreement, we continued with investigating the response of cylindrical support to the pressure pulsation. To be able to do this, it is necessary to establish how the pressure pulsations depend on time. This procedure gives time-dependent functions, which are described below.

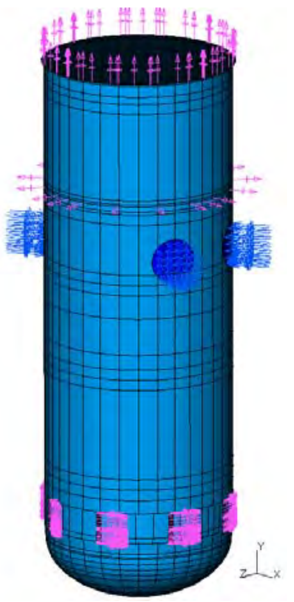

Fig. 5. Calculation model

As in the case of physical start-up, we have chosen five combinations with one to four coolant pumps working in the primary circuit (see Fig. 6). When two actuated pumps were considered, we distinguished if they were placed next or opposite to one another. When calculating forced vibration of the support cylinder, the appropriate pump would enter the calculation by specifying the pressure pulsations on corresponding calculation model circular surfaces.

Comparison of active coolant pumps combinations disclosed that the support cylinder oscillates at the most, when two opposite pumps are actuated.

Cyclic stress determined for high-cycle lifetime was compared with the value presented for the given steel in the standard ASI, Section III from 1996. Thus, the conclusion was drawn that the material of the support cylinder is appropriate with respect to the found stress state.

Excitation. The report on measurements shows that the amplitude of the resulting excitation is 0.04 MPa maximum when four pumps are working. All other combinations give the value of 0.06 MPa at most. Since we don't know precisely which are the proportions of frequency components in the resulting excitation, we have chosen the coefficients 0.7, 0.5, 0.3, and 0.1 for double, triple, quadruple, and quintuple circular frequency resp. Sextuple frequency is identical with the blade frequency so that we assign the weight of 1 to it just as in the case of circular frequency. To express the harmonic trend in behavior of these partial excitations, we have chosen the function of sinus because its value is zero for the zero argument. This approach leads to the effect that the transient gets rapidly steady because only velocity will be non-zero for the initial time point. The velocity will cause only small oscillation at the beginning of the process investigated. Initial displacement and acceleration will be zero.

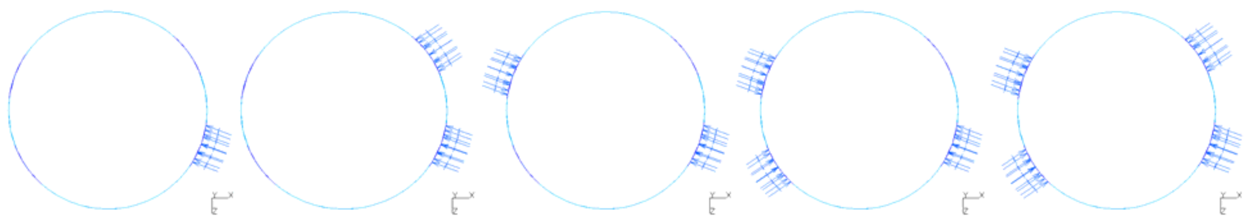

Fig. 6. Excitation for different numbers of actuated main coolant pumps

We have devised the following formula for excitation with four pumps actuated

$$p = 0{,}017\left[\sin\left(\pi \cdot 33{,}\overline{3} \cdot t\right) + 0{,}7 \cdot \sin\left(\pi \cdot 2 \cdot 33{,}\overline{3} \cdot t\right) + 0{,}5 \cdot \sin\left(\pi \cdot 3 \cdot 33{,}\overline{3} \cdot t\right) + \right.$$
$$\left. + 0{,}3 \cdot \sin\left(\pi \cdot 4 \cdot 33{,}\overline{3} \cdot t\right) + 0{,}1 \cdot \sin\left(\pi \cdot 5 \cdot 33{,}\overline{3} \cdot t\right) + \sin\left(\pi \cdot 6 \cdot 33{,}\overline{3} \cdot t\right)\right],$$

where p denotes instantaneous value of pressure, t is time, and the coefficient of 0.017 was selected in such a way so as the resulting excitation amplitude is 0.04 MPa. With the exception of this coefficient, the relation employed for specifying pressure pulsations to be used in other combinations with less then four actuated pumps is identical. The coefficient of 0.0255 replaces the coefficient of 0.017 in the formula.

Dynamical response calculation. We have calculated five variant cases, in which we investigated time-dependent trends in behavior of deformation and stress of VVER 1000 reactor support cylinder. To receive steady initial amplitude caused by non-zero initial velocity, we had to select sufficiently great time interval. As a result, we made our computations in the range from 0 s to 0.6 s with step 0.001 s. We regard the time step as sufficiently small because the maximum frequency contained in specified excitation (100 Hz) has period of 0.01 s. The shortest period found among the harmonic excitation components is thus divided into ten computation time steps.

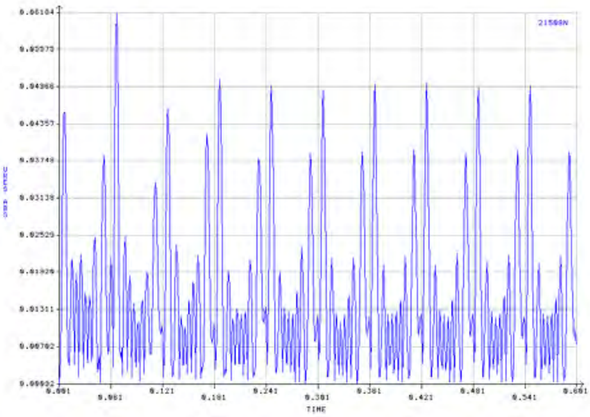

Fig. 7. Deformation dependent on time

We will describe the computational procedure for one actuated pump. As first, given pressure pulsations distribution, we computed corresponding time-dependent behavior of deformations. Fig. 7 shows this behavior for the first variant case.

It indicates that, actually, only small amplitude occurred at the beginning of the process. The process got steady very soon and several practically identical periods of steady-state forced vibration took place. A node in the middle of an excited area lying on the support cylinder surface was selected for plotting this diagram because we anticipate one of the greatest responses to the given excitation to occur here. Fig. 8 is a plot of the same diagram detail near one of the peaks in steady state area. Using it, we can determine the time point (0.427 s in this case), at which maximum deformation occurs and consequently even maximum deformation at the given location of the support cylinder.

After having computed stress state in the given time point and for all elements of the calculation model, we can check if the specified point at the specified time point is really a location of maximum total deformation in steady nominal state. Fig. 9 suggests that maximum stress of the support cylinder with one main coolant pump actuated is approximately 1.6 MPa at this place. Maximum resulting stress state takes place, as is the case with other variant cases, at the radial support its value being approximately 2.24 MPa. This value is probably somewhat greater than the actual one because the support cylinder bears on the pressure vessel, which is yielding. We have modeled this support relative to a fully stiff base. Maximum deformation of the support cylinder is less than 0.07 mm (see Fig. 9).

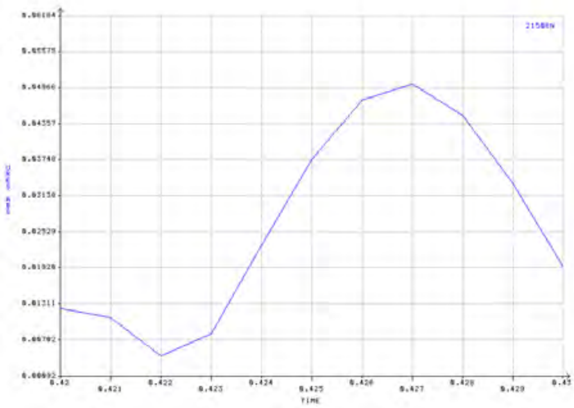

Fig. 8. Deformation distribution in detail

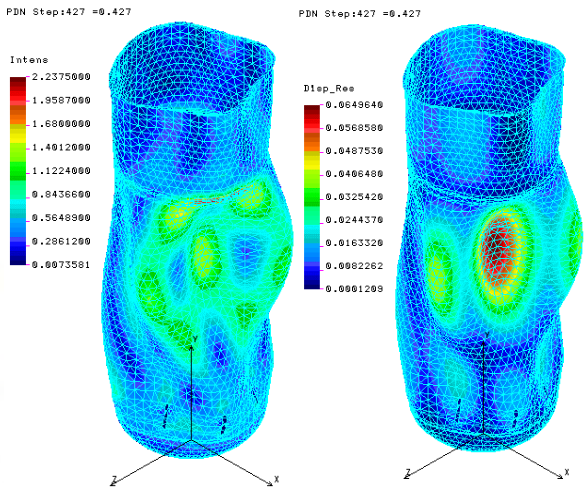

Fig. 9. Stress and deformation in support cylinder

We have adopted the same calculation procedure even for other variant cases. Tab. 1 presents values of maximum stresses and deformations for all variant cases. Obviously, the worst variant case is case No. 3 when two main coolant pumps of the primary circuit loops are working against one another.

Case No.	Max. stress [MPa]	Max. deformation [mm]
1. - one main coolant pump	2,24	0,065
2. - two MCP next to one another	1,90	0,043
3. - two MCP against one another	4,05	0,154
4. - three main coolant pumps	1,33	0.049
5. - four main coolant pumps	1,36	0,047

Tab. 1. Summary of maximum stresses and deformations

Based on these results, we have evaluated high-cycle lifetime of the support cylinder loaded by pressure pulsations. Standard [3] presents a calculation lifetime curve for the austenitic steel of the support cylinder. The curve is shown in Fig. 10.

The conditions for application of the curve are, by the Standard [3], as follows:

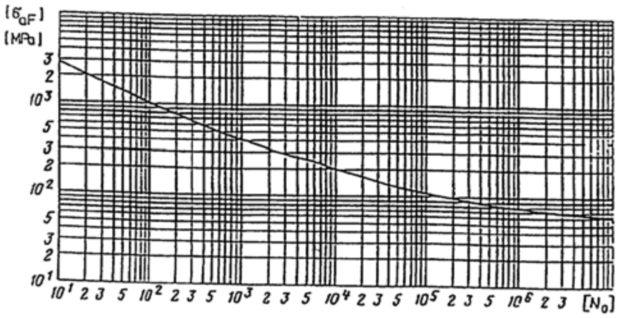

Fig. 10. Calculation lifetime curve according to ASI

- Temperatures in the range from 20°C to 450°C; operational temperature of the core barrel is 350°C.
- $R_{p0,2}/R_m \leq 0{,}7$. For core barrel material, the rate of 0,4 is applicable.
- Ductility $Z \geq 45$ %. For core barrel material $Z = 50$ %.
- $E = 1{,}73.10^5$ MPa. For core barrel material $E = 2{,}05.10^5$ MPa.

Accordingly, the lifetime curve presented in the Standard [3] is applicable for material of lower stiffness. Actual curve for core barrel material would have greater σ_{aF} in the whole range.

We can therefore conclude that the stress state due to pressure pulsations is so low under all regular service conditions as not to influence the lifetime of the VVER 1000 reactor support cylinder.

FREQUENCY ANALYSIS OF PORTION OF 1000 MW TURBINE STEAM PIPING

The question is piping of the turbine installed in the nuclear power plant Temelín. This part of the steam piping exhibited excessive vibration in the course of final testing. It was one of four pipings with diameter Js 600, which feed the turbine with steam. Calculation model of this portion is shown in the Fig. 11. We have created an independent model of the internal part of the diffuser so as to be able to find normal modes of vibration, which can be excited more intensely by pressure vibrations. This model is shown in Fig. 12.

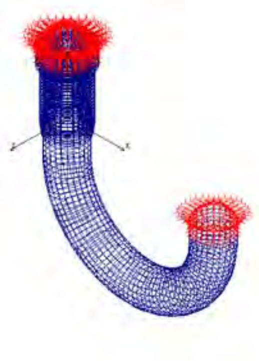

Fig. 11. Calculation model of piping bend

Frequency-modal analysis of both models was performed. The computation results were compared with measurements, which were provided by the ŠKODA Research s.r.o. staff. Significant radially pulsating modes of the diffuser were measured even on the piping (see Fig. 13).

Next, we investigated the pressure pulsations that emerged in the vent diffuser from the point of view of their impact on various types of normal modes. It follows from the analysis that the two-mantle diffuser is dynamically ill-fitting and is acting as a resonator in wide band of frequencies.

At a time when we were busy with these computations, the through-flow part of the vent was adapted so as to cut the low-power excitation (pressure pulsations) in half approximately. To reach further vibration damping, we proposed to replace the diffuser with a single-mantle one of greater wall thickness, or/and to replace the whole piping with thicker one whose natural frequencies would not be in the excitation band.

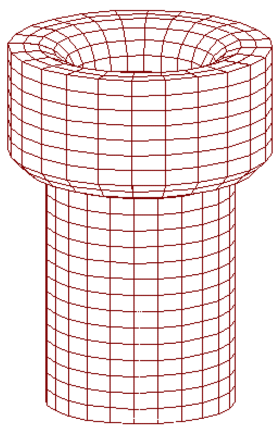

Fig. 12. Diffuser internal part

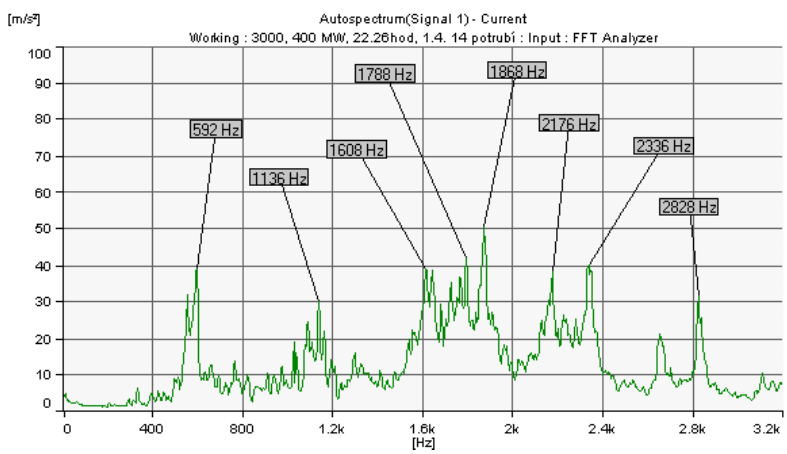

Fig. 13. Spectrum of piping acceleration - measurement

CASK FOR TRANSPORTING SURVEILLANCE SAMPLES

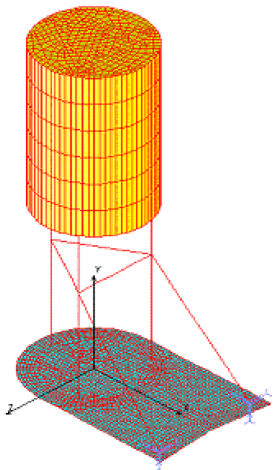

Fig. 14. Calculation model

One of the areas, which we deal with in our department regularly, is the calculation of casks for transporting irradiated materials or emitters. As an example of such calculation can serve stress, stability, and seismic analyses of the cask ŠKODA TKSV-1000 that is intended for transporting surveillance samples of VVER 1000 reactor pressure vessel material.

The cask strength was evaluated partly for the cask on its own and partly for its stand, which is located in the plant. This evaluation was restricted only to checking the hinge pins and lifting lug when in transport, and to verifying that it would withstand external over-pressure if immersed to a depth of 15 m because the internal over-pressure is zero while the cask is in service. This calculation replaced the “Immersion test” described in the Regulation No. 142/1997 Coll., Appendix No. 6 applicable at that time. The strength evaluation of the cask stand was made considering the cask dead weight and stand dead weight. Seismic analysis was performed for a cask placed on its stand in the plant.

Fig. 14 presents a calculation model of the cask placed on stand, which is bolted down to the floor by two bolts M 80×6. The device has been loaded both by its dead weight and seismicity for all service conditions. The dead weights of the cask and its stand are 4060 kg and 420 kg respectively. Dynamic load is defined by the response spectra, which are depicted in the Fig. 15. The excitation was specified for the corresponding floor of the reactor building (28.0 m). To be sure that the calculations are conservative enough, we have chosen the damping to be only 2 per cent.

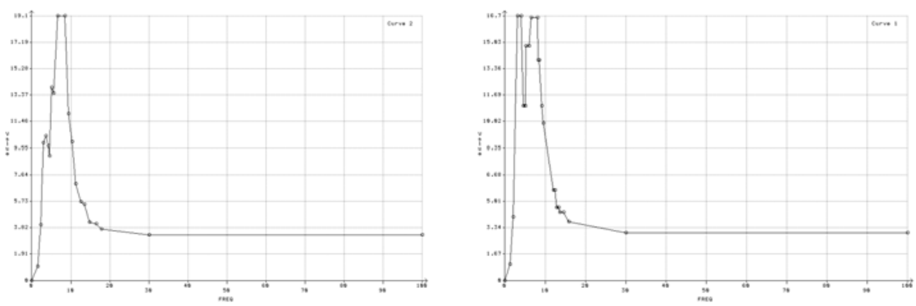

Fig. 15. Envelope response spectra, vertical and horizontal

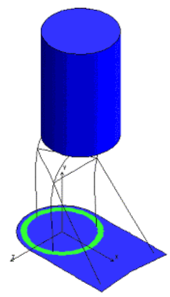

Fig. 16. Stability 1. mode

Fig. 16 presents first mode of the stand buckling when loaded by its dead weight and cask weight.

Frequency-modal analysis was again performed, and forced vibration of the cask on the stand was calculated for given response spectra. Since the given response spectra show maximum acceleration around 10 Hz and have been specified up to 33 Hz, we have computed first ten normal modes of vibration. Taking into consideration that the ninth normal mode has the frequency 84.1 Hz and that the first eight normal modes lie in the range of the specified response spectra frequencies, this number is sufficient.

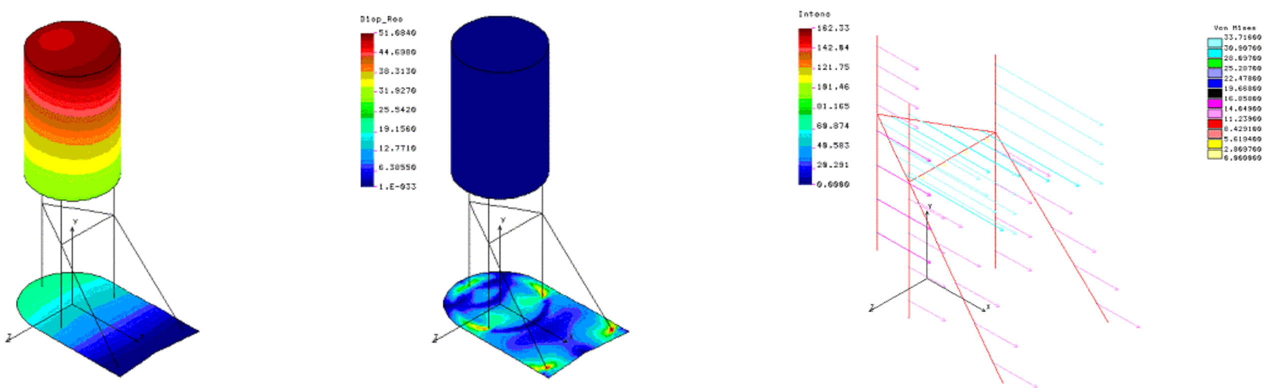

Fig. 17. Deformation and stress state in seismic excitation

Fig. 17, on the left, shows resulting deformation and stress state according to the Tresca hypothesis. In the middle, we can see the stress state in the base plate, and the stress state in the beams of the stand is plotted in form of vectors on the right.

All stresses worked out sufficiently low and met requirements of applicable standards.

INTERNAL PARTS OF FOUR NPP KOZLODUY UNITS

The calculations will cover units No. 1, 2, 3, 4 at the Nuclear Power Plant Kozloduy, Bulgaria. The question is resistance of reactor internal parts when loaded statically and dynamically in design service conditions including break of primary circuit piping 100, 200, and 500 mm in diameters and specified seismic loading. Since it is difficult to obtain the underlying data from Bulgaria, obviously the realization of these calculations would be postponed for 2003. Therefore, we will describe only the procedure scheduled for internal parts seismic calculations.

The goal of the analyses is determining the responses and corresponding stress state for internals of four units at NPP Kozloduy. The internal parts are support cylinder with bottom, core basket, and protecting tube system of the nuclear reactors VVER 440, type V230. The excitation will be represented by given response spectra at the attachment of the pressure vessels to their base on the appropriate floor of the building.

We are creating simplified calculation models of entire reactors in co-operation with the staff of the Chair of Mechanics of the West-Bohemian University in Plzeň. They are amenable to the excitation corresponding to the specified response spectra (time-dependent behavior of acceleration) and there will be determined corresponding trends of acceleration at internals attachment. The time-dependent trends of acceleration at internals attachment will be converted into responses, which will be subsequently applied to detailed calculation models of the internal parts. In the manner as described, the responses of internals will be computed on the earthquake defined by the response spectra for the floor on which the reactor is mounted.

The calculations will be performed for so called maximum calculational earthquake (corresponding to SSE) and design earthquake (corresponding to OBE). There will also be specified response spectra or time-dependent trends in behavior of two horizontal and one vertical components of the earthquake. The damping coefficient k will be set to 0.02. All parts subject to computations will be checked if they withstand current normal operation loading and SSE or OBE.

The lifetime will be judged by the Standard [4], Paragraph 5.11.2.14. The earthquake will be included only if the damage determined by lifetime computations exceeds the value of 0.8. If there is need of performing this calculation, we will consider the combination of normal operation loading and OBE. We will consider 50cycles.

CONCLUSION

The contribution presents several problems in the field of stress, thermal, dynamical, and lifetime analyses that are being performed in ŠKODA JS a.s. Another three groups in the Calculations Department are engaged in the thermohydraulic, physical, and shielding calculations. Thus, the co-operation of several departments gives ŠKODA JS a.s. its capacity to cover a wide range of problems that are necessary to be solved for developing and manufacturing safe nuclear facilities.

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