IMPACT OF CORE INTERTIAL PROPERTIES ON DYNAMIC CHARACTERISTICS OF WWER-1000 REACTOR BARREL

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Abstract

An investigation into dynamic characteristics of the barrel-core system has been undertaken to evaluate the impact of core inertial properties on the dynamics of the barrel. The study revealed some specific dynamic features of the system. The calculated results were supported experimentally by tests.

Introduction

Transverse beam-type vibrations of the core barrel, a major load-carrying component of the reactor, constitute the greatest hazard to PWRs. An investigation into dynamic characteristics of the barrel-core system has been undertaken to evaluate the impact of core inertial properties on the dynamics of the barrel.

The core inertial properties depend on the specific features of the WWER-1000 reactor (Figure 1). The mass of the core is much more than that of the barrel. Large dimensions of the core require that rotation inertia should be taken into account. Placement of a core into a barrel leads to initial deflection of the centre of masses (CM) from the geometrical centre of the conjugation section (GCCS) in the barrel-core system. Our paper describes the core as an inertial non-deformable body (INB) which features all the characteristics mentioned above, namely the mass, inertia mass moment (IMM) and deflection of the mass centre (MC) from the geometrical centre of the conjugation section. When evaluating these characteristics we regard the barrel bottom and shield as part of the INB (Figures 1,2). The barrel dynamics are described by the Bernoulli beam equation and that of full moment shell theory. Both models are extensively used in calculations and diagnosis of reactors [1,2]. The core barrel is rigidly fixed at the dividing ring cross-section but is free at the bottom (Figure 2). Initially a wide analysis of the dynamic behaviour of the system was performed, with interaction between the inertial and elastic elements investigated in the form of a simplified problem (see the section entitled *Dynamic properties of the two-element base system*). The calculated results used to describe the simplified models were supported experimentally by tests. The comprehensive study of INB impact on the dynamic properties of the simplified system in question allowed us to solve the problem of calculating the dynamic characteristics of the barrel-core system of WWER-1000 reactor (see the section entitled *Dynamic characteristics of the barrel-core system*).

Dynamic properties of the two-element base system

Let us consider a system (Figure 3) which consists of two elements – console inertial beam (CIB) and inertial non-deformable body. The system is a simplified (base) version of approximation of an object (Figure 2). Although the parameters of the base system do not match those of a specific object, the former has similar properties.

Let us discuss the dynamic properties of the six models of the base system (Figure 3). The models varied in a degree of the INB inertial properties taken into account. In particular, they were discounted in the first model which was the simplest one. The INB was simulated as a point mass in the second model and as a body with mass inertial moment and mass centre lying on the connection cross-section plane in the third model. The fourth model has the INB mass centre displaced in relation to the connection cross-section plane along the normal line in the direction of the beam axis (normal deflection of the mass centre – ND). The fifth and sixth models have the mass, inertial moment, and mass centre displaced in relation to the connection cross-section plane along the beam axis (tangential deflection of the mass centre – TD). The former has positive displacement with the mass centre shifted away from the beam while the latter has negative displacement with the mass centre shifted towards the beam.

Figure 1. WWER-1000 reactor

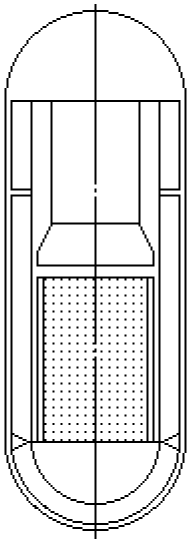


Figure 2. Two-element portion of the reactor

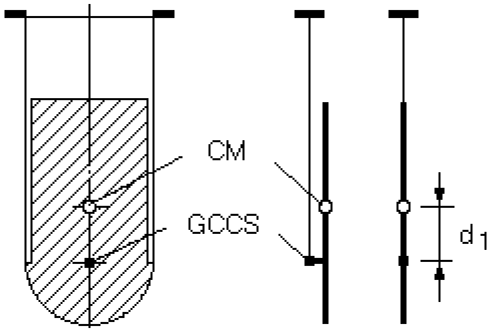
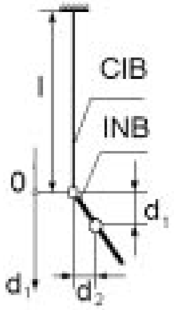
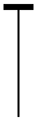
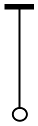
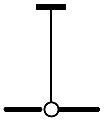
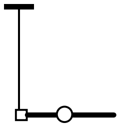
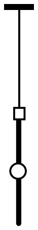
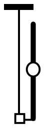


Figure 3. Two-element base system CIB-INB and its six models

System	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
						
d_1 - TD d_2 - ND ○ - CM ▫ - GCCS	$m = 0$ $J_0 = 0$ $d_1 = 0$ $d_2 = 0$	$m \neq 0$ $J_0 = 0$ $d_1 = 0$ $d_2 = 0$	$m \neq 0$ $J_0 \neq 0$ $d_1 = 0$ $d_2 = 0$	$m \neq 0$ $J_0 \neq 0$ $d_1 = 0$ $d_2 > 0$	$m \neq 0$ $J_0 \neq 0$ $d_1 > 0$ $d_2 = 0$	$m \neq 0$ $J_0 \neq 0$ $d_1 < 0$ $d_2 = 0$

The eigenfrequencies of the base system are obtained through the use of two methods such as precise analytic and numerical approximated methods. Both yield approximate results for all six models (Table 1).

Choosing a way of the INB presentation will have a great impact on the eigenfrequencies. An increase only in mass (model 2) or only in inertial moment (model 3) or only in normal deflection of the mass (model 4) lead to a result which seems self-evident, i.e. a decrease in the eigenfrequencies (Figure 4). Impact of the tangential deflection (models 5 and 6) of the mass centre on the frequencies is much more complex (Figure 5). It brings about an increase in the inertial moment as in model 4. Besides, it leads to additional dynamic interdependence (DI) between various degrees of INB freedom. When the INB shifts along the beam axis (i.e. gradual transition from model 5 to model 6) it causes a change in the tangential deflection and dynamic interdependence. DI makes frequency curves asymmetrical, and a maximum at $d_1 = 0$ gives way to an extremum at a certain negative tangential deflection. Any change in the system parameters, e.g. the length of a beam, can make the extremum leave the zone of actual values of the TD (Figure 6). As far the system in question is concerned, the actual values of the TD range between the extreme positions of the INB at $d_1 = \pm 0.275$ m.

When outside of the extremum the shapes of the first and second modes reverse. For a beam 0.25 m long frequencies at $d_1 = 0.275$ m and $d_1 = -0.275$ m appear to be on the opposite sides in relation to the extremum (Figure 6) and succession of forms changes (Figure 7). For a beam 0.75 m long this phenomenon was not observed.

The above-mentioned dynamic properties were supported experimentally by the tests carried out on a number of models. The results of the tests and calculated results are given in Table 2.

Table 1. The eigenfrequencies of the two-element base system

Mod.	Method	f_1, Hz	f_2, Hz	f_3, Hz	f_4, Hz	f_5, Hz	f_6, Hz
1	Analyt.	13.16	82.50	231.0	452.7	748.3	1118
	Numer.	13.13	82.31	230.6	452.3	749.4	1124
2	Analyt.	3.187	58.61	188.0	391.2	668.4	1019
	Numer.	3.187	58.61	188.1	391.7	670.5	1026
3	Analyt.	2.879	12.84	86.34	233.1	454.7	750.3
	Numer.	2.878	12.84	86.35	233.2	455.4	753.2
4	Analyt.	2.257	8.266	85.72	232.8	454.6	750.2
	Numer.	2.257	8.266	85.72	232.9	455.2	753.2
5	Analyt.	1.664	18.80	93.62	240.2	461.5	756.9
	Numer.	1.663	18.79	93.61	240.2	462.2	759.8
6	Analyt	5.537	6.299	87.06	235.6	458.1	754.1
	Numer.	5.536	6.298	87.07	235.7	458.8	757.1

Figure 4. Impact of mass, central inertial moment of INB and normal deflection on eigenfrequencies.

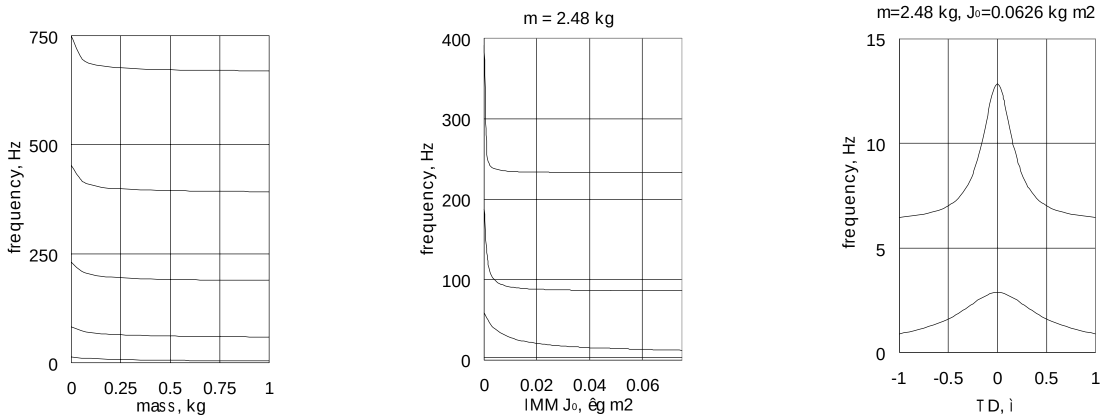


Figure 5. Impact of dynamic interdependence between the forward and rotational degrees of INB freedom on the eigenfrequencies

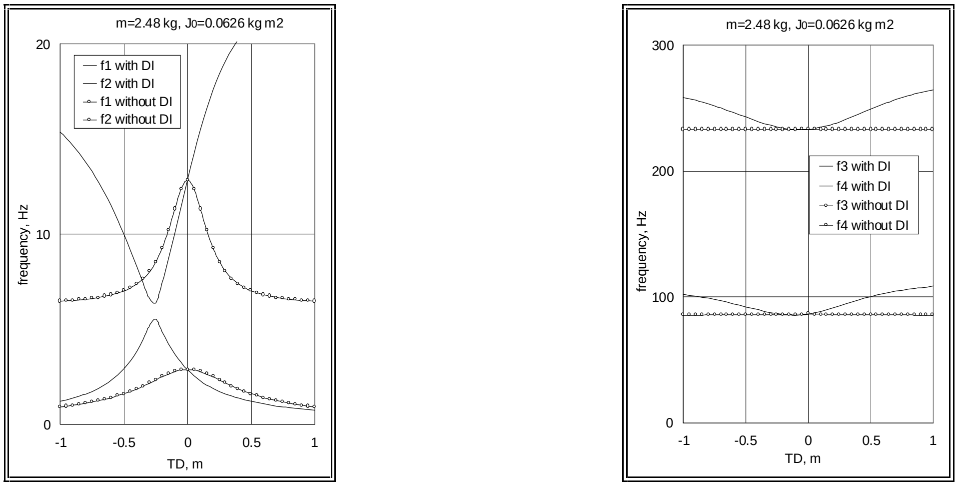


Figure 6. Change in diagram type resulting from a change in a certain parameter of the base system

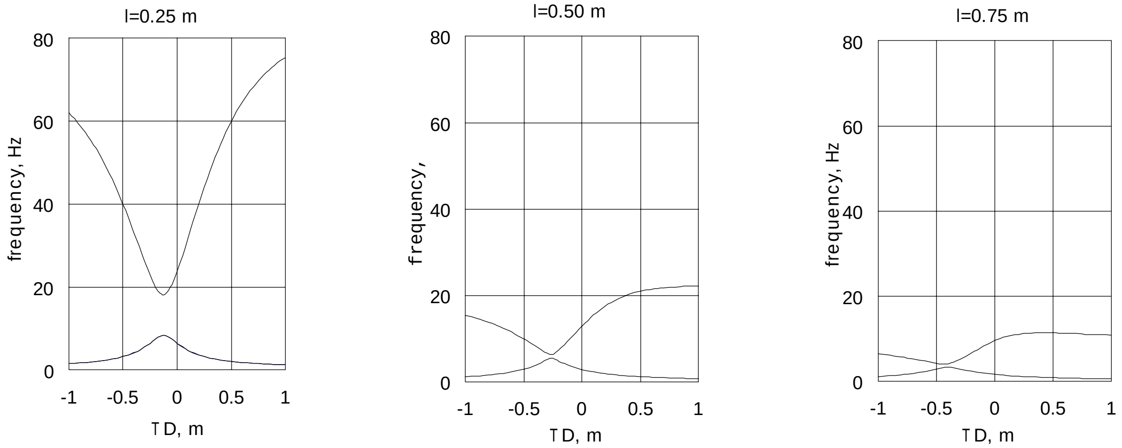


Figure 7. Change in succession of shapes when outside the extremum of the frequency-TD function

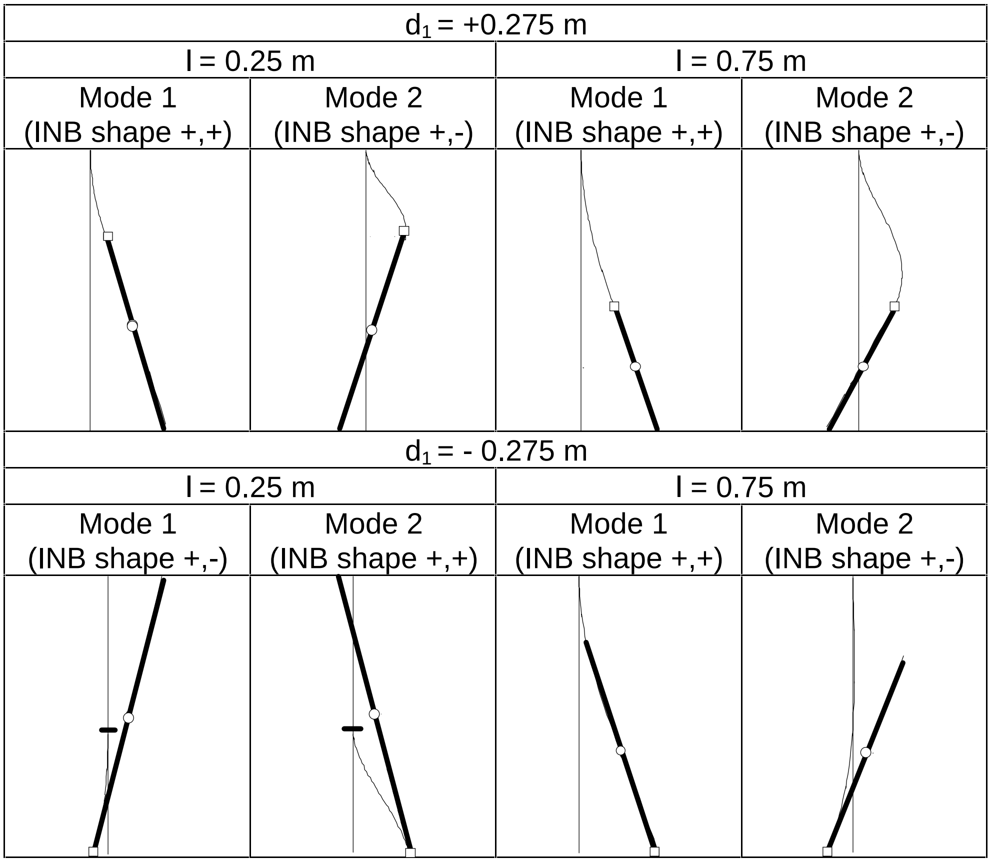


Figure 8. Four variations of the experimental model

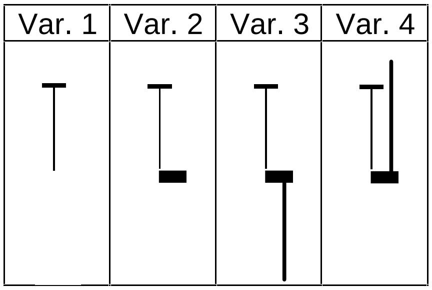


Table 2. Calculated and experimental results

Variant	Method	f_1, Hz	f_2, Hz	f_3, Hz	f_4, Hz
1	Numeric.	27.43	171.90	481.32	943.19
	Experim.	27.6	172	482	910
2	Numeric.	14.04	124.1	337.5	636.2
	Experim.	14.4	129	354	648
3	Numeric.	3.428	31.52	203.5	537.58
	Experim.	3.4	32.2	-	-
4	Numeric.	7.504	15.12	169.9	533.2
	Experim.	7.6	15.3	-	-

Dynamic characteristics of the barrel-core system

Let us determine the eigenfrequencies and shapes of WWER-1000 reactor barrel, assess an impact of the TD and see whether it is possible to use beam equations for a description of the barrel dynamics.

The eigenfrequencies obtained in the beam model for barrels considerably differ from those calculated on the shell model with the main mode frequencies being 1.4 times as high in the former (Table 3). The dynamic characteristics (beam model) are shown in Figure 9.

Because of the design features of WWER-1000 reactor the way of the core presentation (point mass, INB which has a mass and inertial moment or INB which has a mass, inertial moment and TD) will have a great impact on the results obtained. Taking into account all the inertial properties of the core, namely, its mass, inertial moment and tangential deflection of the mass centre we can achieve a threefold decrease in the first eigenfrequency (for shell barrel model) (Figure 10). Failure to take into consideration the dynamic interdependence results in cutting the main mode frequency by roughly 20%. The negative-positive reversal of the deflection leads to about a 30% reduction in the eigenfrequency. The succession of mode shapes is conventional in the barrel-core system which means that the frequencies are located to the right of the extremum.

Eigenfrequencies and shapes of the system were determined which was made possible with the use of an original method of calculations. The C++ program permitted us to specify oscillation eigenfrequencies and shapes for various types of barrel-core connections as well as for models with spring supports.

Table 3. Frequency spectrum of the barrel-core system

Beam model							
25.07	66.28	-	-	-	-	-	-
Shell model							
18.09	48.35	162.1	292.6	367.7	400.7	422.9	438.7

Figure 9. Dynamic characteristics of WWER-1000 reactor barrel with regard to the core (beam theory)

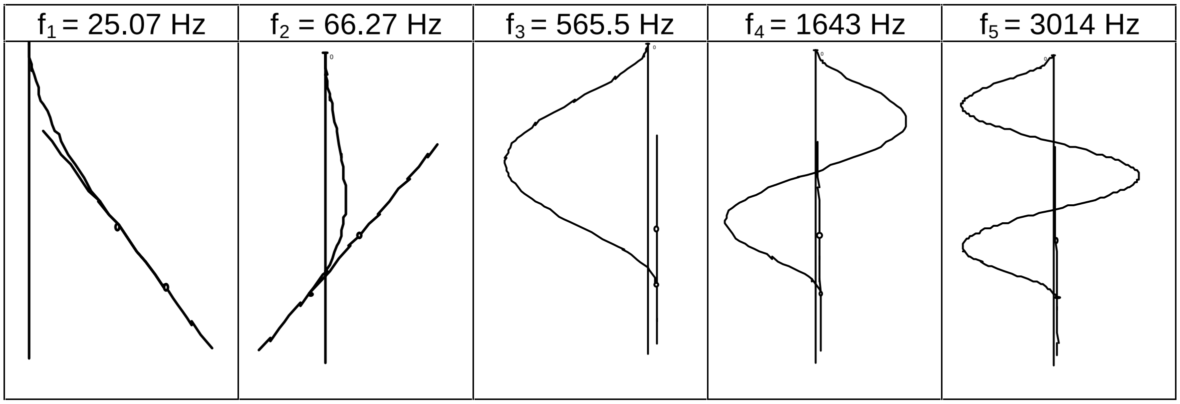
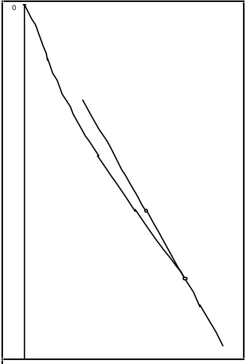
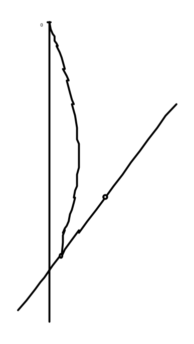
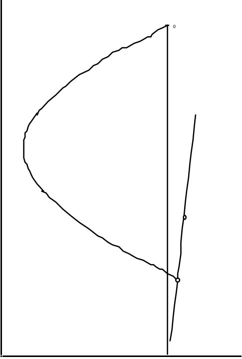
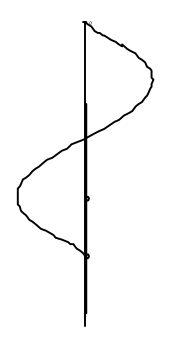
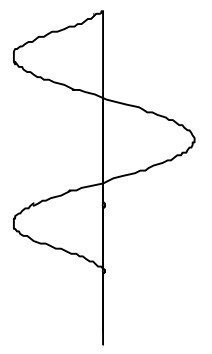
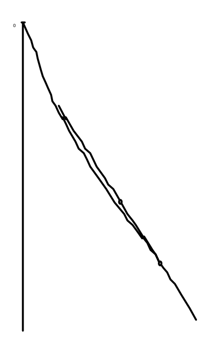
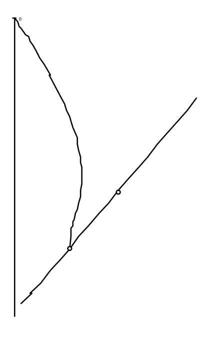
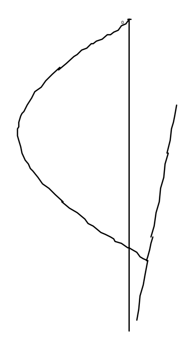
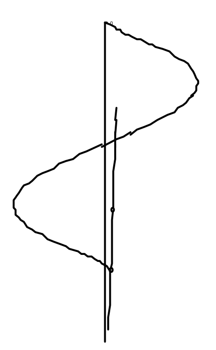
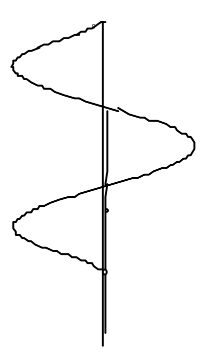
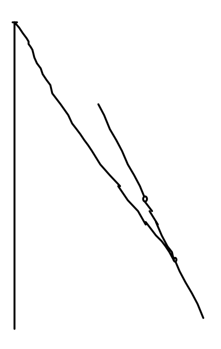
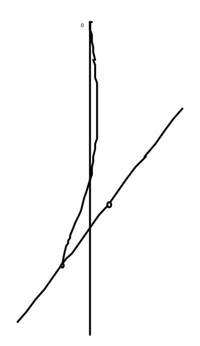
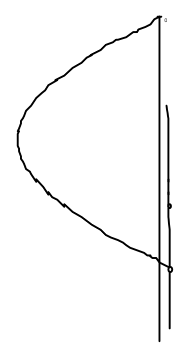
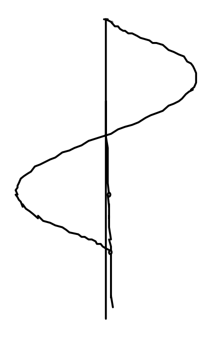
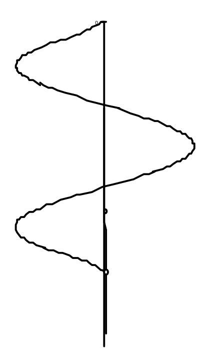


Figure 10. Dynamic characteristics of WWER-1000 reactor barrel with regard to the core (shell theory)

<table>
<tr><td colspan="5">Without regard for dynamic interdependence. The tangential deflection of the mass centre has been taken into account only when calculating the inertial moment</td></tr>
<tr><td>f_1 = 14.96 Hz</td><td>f_2 = 58.50 Hz</td><td>f_3 = 164.1 Hz</td><td>f_4 = 291.5 Hz</td><td>f_5 = 367.3 Hz</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">TD is considered to be positive and is taken into consideration both in determining the inertial moment and in introducing the dynamic interdependence</td></tr>
<tr><td>f_1 = 12.33 Hz</td><td>f_2 = 67.38 Hz</td><td>f_3 = 171.1 Hz</td><td>f_4 = 292.7 Hz</td><td>f_5 = 367.8 Hz</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">TD is considered to be negative and is taken into consideration both in determining the inertial moment and in introducing the dynamic interdependence</td></tr>
<tr><td>f_1 = 18.09 Hz</td><td>f_2 = 48.35 Hz</td><td>f_3 = 162.1 Hz</td><td>f_4 = 292.6 Hz</td><td>f_5 = 367.7 Hz</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
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Conclusions

- An investigation of dynamic properties of the system consisting of an elastic element and an inertial non-deformable body has been undertaken. It is shown that INB which has a certain mass, inertial moment and deflection of the masses' centre from the conjugation section adds a number of substantial dynamic properties to the CIB-INB system. In particular, TD brings about a strong dynamic interdependence between the forward and rotational degrees of freedom, an extremum of characteristics such as tangential deflection-frequency, and a change in succession of shapes when outside of the extremum.

- The problem of calculating the dynamic characteristics of the barrel-core system has been solved. It was demonstrated that for barrel, the eigenfrequencies obtained on the beam model considerably differ from those calculated on the shell model with the main tone frequencies being 1.4 times as high in the former.

- Because of some design features of WWER-1000 reactor the way of the core presentation (point mass, INB which has a mass and inertial moment or INB which has a mass, inertial moment and TD) will have a great impact on the results obtained. Taking into account all the inertial properties of the core, namely its mass, inertial moment and tangential deflection of the mass centre we can achieve a threefold decrease in the first eigenfrequency (for shell barrel model). Failure to take into consideration the tangential deflection results in cutting the main mode frequency by approximately 20%. The negative-positive reversal of the displacement leads to about a 30% reduction in the eigenfrequency.

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[1] J. Uchiyama, K. Sakai. A Reactor Equipment Monitoring System for Japanese PWRs. SMORN VII, 1995.

[2] E. Altstadt, G. Grunwald, F.-P. Weiss. Theoretical Vibration Model of VVER Reactors Considering Fluid-structure-interaction. SMORN VII, 1995.