Determination of types and degree of corrosion damage of fuel cladding by informative ranges of divergences of their natural oscillation frequencies

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Abstract: The urgency of the work consists in using a new approach to the definition of informative frequencies for the identification of corrosion damage. The aim of the work is to determine the discrepancies between the resonance frequencies of the oscillations of the fuel casing segments of the factory geometry and with various types of corrosion damage obtained by modelling defects in the casings of fuel casing segments. As a result of the analysis, informative ranges of ordinal numbers were revealed, which allow to determine the following corrosion damages: thinning from the outer and inner sides of the fuel casing, pitting corrosion, fretting corrosion.

1. Introduction

Diagnostics of corrosion damage is of great importance for the timely prevention of the fuel elements destruction. Nowadays a lot of methods of corrosion damage control of structures are known and used. They are electromagnetic, electric, thermal, magnetic methods and methods of metallography. However, for the study of corrosion of fuel cladding in hot (protective) chambers, due to the specifics of the research conditions — radiation from the studied samples of materials, only electromagnetic [1-2], electrical [3] and acoustic methods [4-6] are used, which belong to the category of non-destructive testing methods.

Currently resonant acoustic methods use an experimental set of resonant peaks of the amplitude-frequency characteristic, the values of frequencies and q-factors of which vary depending on the presence of a corrosion damage. Acoustic resonance methods generally operate at frequencies from 100 kHz to 1 MHz. One of the tasks of the work was to verify the assumption about the existence of order number ranges of natural vibration frequencies of the BN-600 reactor fuel claddings. It is possible to identify various kinds of corrosion damage via these ranges. Fuel elements of fast breeder reactor is characterized by the following types of corrosion: general, pitting, intergranular and stress corrosion cracking [7]. Currently existing methods of identification any type of corrosion damage of spent fuel elements are destructive.

The structure of our work is as follows: in the section 2 we show the results of calculation cladding frequencies via finite element method. In the section 3 we quite extensively describe frequency difference between a fuel element without any types of corrosion and corroded fuel elements. Finally in the section 4 we discuss important results and state prospects for future work.

2. Calculation of natural frequencies of short segments of fuels claddings by the finite element method

The studies were carried out by analyzing the graphs of differences of resonant vibration frequencies of fuel element claddings of factory geometry and fuel elements with corrosion damage. Resonance frequency values are obtained by simulation finite element analysis (see Figure 1) in SolidWorks CAD.
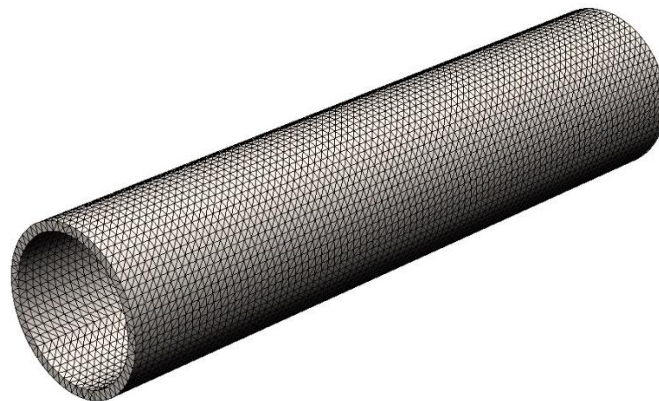

Figure 1. The mesh of finite element analysis of fuel element with factory geometry

The calculations were carried out for fuel element segments 30 mm long, with an external diameter of 6.9 mm and a thickness of 0.4 mm. There are about 900 resonant frequencies in the range from 1 kHz to 1 MHz for the cladding of the BN-600 fuel element with a length of 30 mm. The material of the fuel element — CHS-68 (06H16N15M2G2TFP) [8]. The calculated frequencies were determined for fuel elements with the following corrosion protection: uniform thinning of the inner diameter on the 1 and 5 microns, uniform thinning on the outside side 1 and 5 microns, uniform thinning with internal and external parties on 1 and 5 microns, the fuel elements with 15 and 300 foci of pitting corrosion with a diameter of 50 μm and depth 30 μm, the fuel element with fretting corrosion, which is a spiral groove depth of 10 microns and a pitch of 100 mm.

3. Corrosion damage of fuel cladding of BN-600 reactor. Frequency range differences

In studies as a reference sample was adopted fuel element with factory geometry having nominal geometric dimensions and which has no corrosion damage. All calculated simulation data are compared with the factory geometry fuel element (FGF). We compared resonant frequencies FGF and fuel elements with external thinning of 1 μm (FET1), the one with external thinning 5 microns (FET5), the one with internal thinning 1 μm (FIT1) and fuel element with internal thinning 5 microns (FIT5) in the most informative frequency ranges under serial numbers 629 — 652, 670 — 673 and 708 — 713. Graphs are plotted for all ranges of informative resonant frequencies.

Figure 2 presents the resulting graphs, the discrepancy of resonant frequencies FGF with FET1, FET5, FIT1 and FIT5 in the frequency range under order numbers 629 — 652 and 708 — 713 respectively. According to the graphs it is possible to identify the internal and external thinning: if the thinning on the outer side of the fuel element cladding, then on the frequency range under the order numbers 708 — 713 the values of the differences of resonant frequencies are in the negative region, if the thinning on the inner side of the fuel element cladding — the values of the differences of the resonant frequencies are in the positive area. Range 670 — 673 is uninformative for this type of corrosion because frequency difference changes its sign many times in this interval of order numbers.
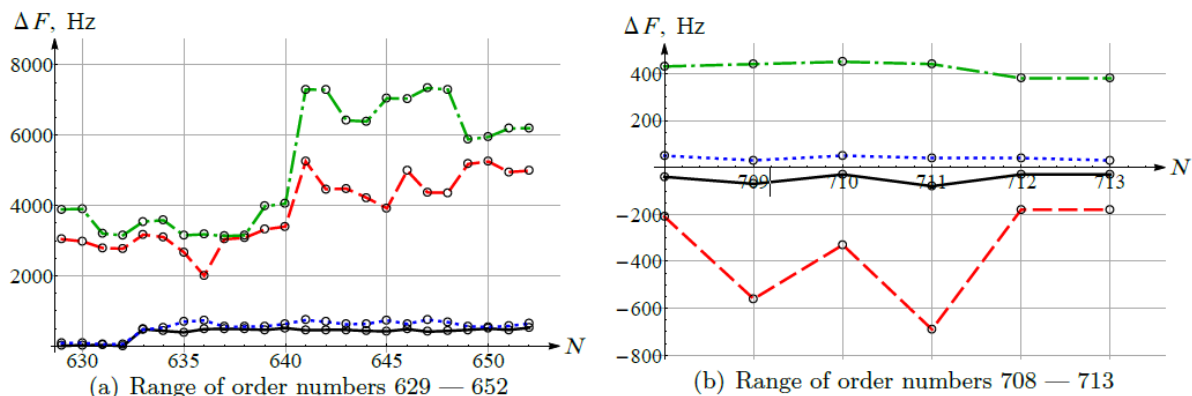
(a) Range of order numbers 629 — 652   (b) Range of order numbers 708 — 713

Figure 2. Figure 2. The dependence of frequency difference between FGF and FET1 (solid black curve), FET5 (red dashed curve), FIT1 (blue dotted curve) and FIT5 (green dashed-dotted curve) on order numbers

In the case when there is a thinning of fuel element claddings both from the inside and from the outside, the values of the differences of the natural frequencies of fuel element claddings vibrations are orders of magnitude higher and are located in both positive and negative areas. Informative frequency ranges for clarification on both sides of the fuel element cladding are ranges with ordinal frequency numbers 629 — 652, 670 — 673, and 708 — 713. Natural oscillation frequencies of fuel element claddings with different types of thinning are located in the positive region (see figure 3(a)). The discrepancies of the natural frequencies of the fuel element claddings factory geometry with the natural frequencies of vibrations of fuel element claddings with various thin places in the other ranges (figures 3(b) and 3(c)) necessary to identify other corrosion damage. The graphs in figure 3 were obtained for fuel elements with internal and external thinning of 1 μm (FEI1).

We also studied differences between the resonant frequencies of FGF and fuel element with 15 centers of pitting corrosion (FMP) and one with 300 centers of pitting corrosion (FBP) in the frequency ranges under the order numbers 629 — 652 and 670 — 673, see figures 4(a) — 4(b). Now we can identify pitting corrosion damage, and, if they are few, the graph is in the positive area; if pitting corrosion damage is greater, the graph moves from the positive area to the negative and the divergence of the oscillation frequencies of fuel cladding increases. Order numbers 708 — 713 are uninformative for such type of corrosion because frequency difference changes its sign many times.

Besides pitting corrosion we have investigated fretting corrosion. The figure 5 shows differences between the resonant frequencies of FGF and fuel element with fretting corrosion (FFC) in range of order numbers 629 — 652. Note that in small interval 629 — 632 the sign of difference is positive and in other numbers it is negative. Ranges 670 — 673 and 708 — 713 are characterized by positive values (100 — 200 Hz) of frequency difference for fretting corrosion. These graphs are sufficient for unambiguous identification of FFC, and in the frequency ranges under the order numbers 629 — 632 the values for this corrosion damage are located only in the positive region.

The results of the analysis are presented in the Table 1, according to which it is possible to determine the type and degree of corrosion damage.
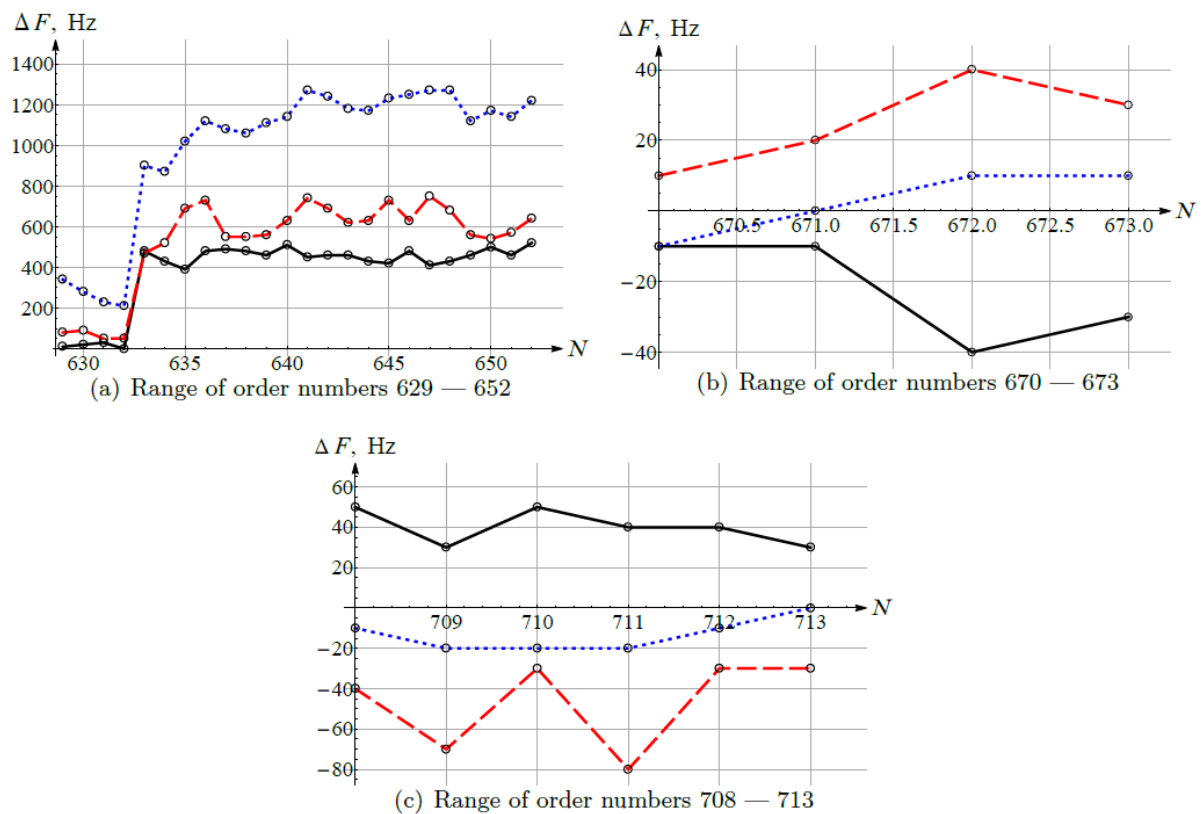
(a) Range of order numbers 629 — 652

(b) Range of order numbers 670 — 673

(c) Range of order numbers 708 — 713

Figure 3. The dependence of frequency difference between FGF and FET1 (solid black curve), FIT5 (red dashed curve), FEI1 (blue dotted curve) on order numbers
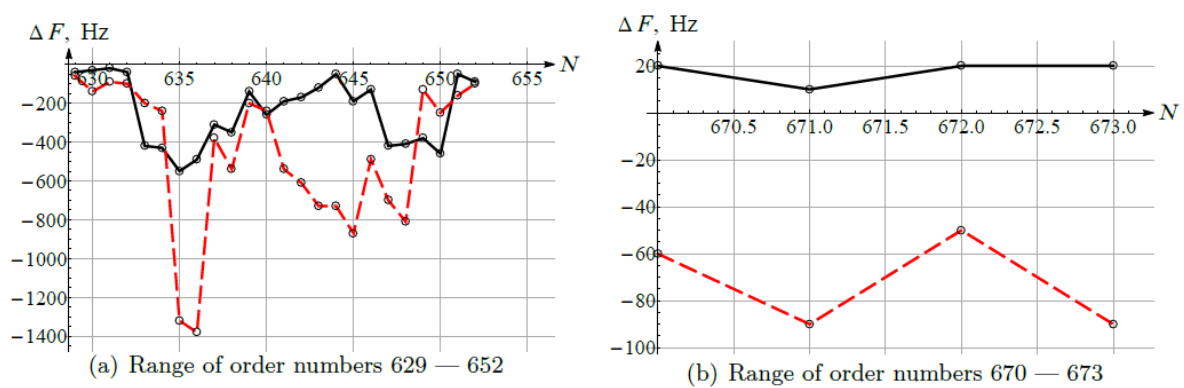

(a) Range of order numbers 629 — 652

(b) Range of order numbers 670 — 673

Figure 4. The dependence of frequency difference between FGF and FMP (solid black curve), FBP (red dashed curve) on order numbers.
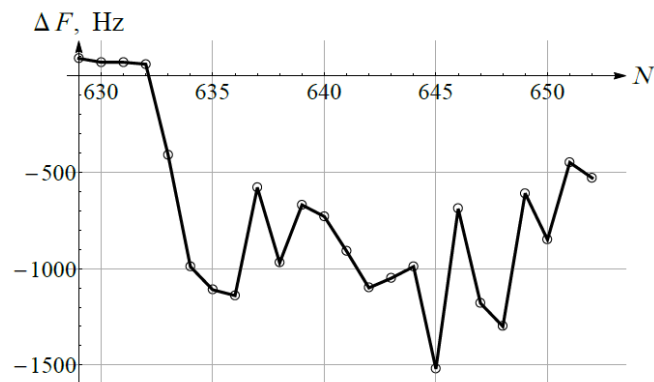
Figure 5. The dependence of frequency difference between FGF and FCF on order numbers.

Table 1. Types of corrosion damages and corresponding areas of divergences of resonant frequencies of vibrations of fuel element claddings of factory geometry and fuel elements with different types of corrosion damages

Type of corrosion damage	Divergence area for sequence number ranges			
	629-632	633-652	670-673	708-713
Internal thinning	Positive		Uninformative	Positive
External thinning	Positive		Uninformative	Negative
Thinning on both sides	Positive		Both areas	Negative
Minimum pitting corrosion	Negative		Positive	Uninformative
Maximum pitting corrosion	Negative		Negative	Uninformative
Fretting corrosion	Positive	Negative	Positive	Positive

4. Conclusion

We analyzed the differences of natural frequencies of claddings of fuel element with factory geometry and corroded fuel elements. It can be approved that suggested method of identifying of corrosion types is valid. The informative ranges of the order numbers corresponding to the divergences between them are determined, with the help of which it is possible to determine the different types and degree of corrosion damage: outer and inner thinning of the fuel element cladding, pitting corrosion, fretting corrosion. We have established three ranges of informative order numbers: 629 — 652, 670 — 673 and 708 — 713. The results of analysis are presented in the Table 1. For the future work it would be better to carry out real experiments and compare experimental and simulated results. Attractive properties of suggested method will form the basis for the creation of a whole complex of facilities for the study of fuel elements. Исследования выполнены при финансовой поддержке

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