CORTEX

Core monitoring techniques and
experimental validation and demonstration

Noise analysis in NPP diagnostic data processing

CORTEX Workshop

Advanced signal processing methods and learning methodologies applied to the monitoring of NPP reactor conditions

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CONTENT

Sources of real plant data

Tools

Identification of reactor phenomena

Scope of operational NPP noise diagnostics

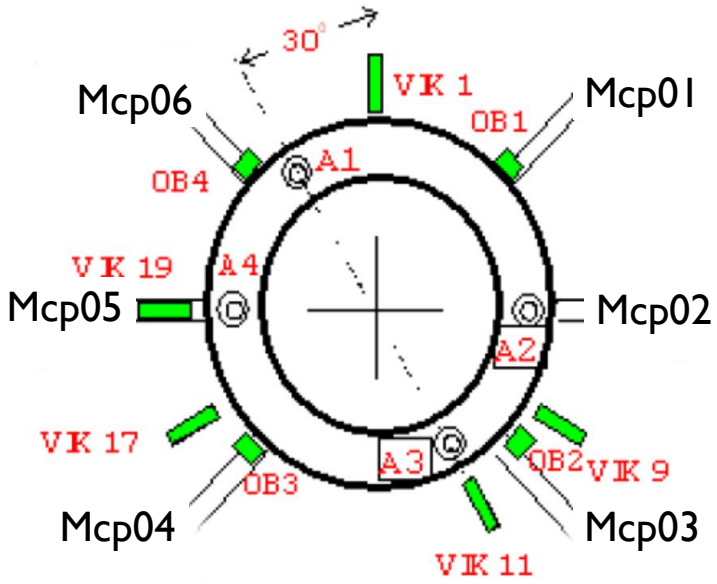
Investigated tasks

Conclusion

Sources of real plant data

Positions absolute displacement sensors/accelerometers, ex-core ionization chambers and self power neutron detectors

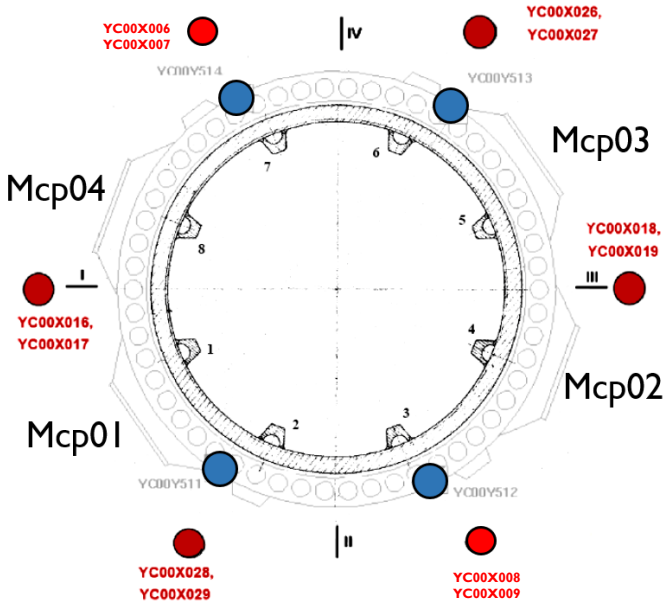
NPP Dukovany

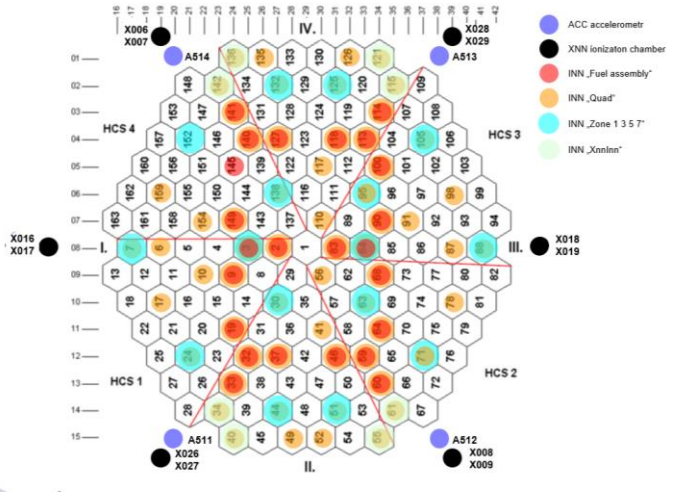


Unit	1	2	3	4	Sensors
Absolute displacement	4	4	4	4	16
Relative displacement	12	12	12	12	48
Acceleration	0	6	6	6	18
Neutron fluctuation	6	6	6	6	24
Pressure fluctuation	0	0	0	2	2
	22	28	28	30	108

A …absolute displacement sensors
VIK …ex-core ionization chambers

NPP Temelin





Unit	1	2	Sensor total	Location
Ex-core neutron noise	8	8	16	Outer upper and lower reactor plane
In-core neutron noise	256	256	512	Reactor internals
Temperature	12	12	24	Reactor outlet
Acceleration	10	10	20	Reactor cover Steam generator
Pressure pulsation	0	5	5	Cold leg pipe
	286	291	577	

A …acceleromters
X …ex-core ionization chambers
I … self power detectors

Tools

UIZ Unified information source

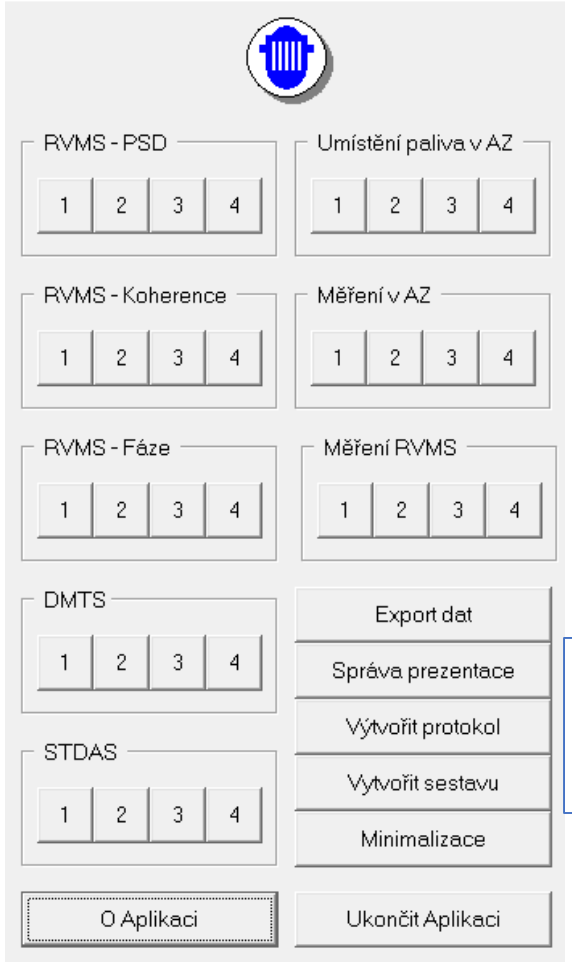
RVMS Power spectral density

RVMS Coherence

RVMS Phase

DMTS measurements

STDAS technological measurements



Fuel set-up load

In-core measurements

Measurement configuration

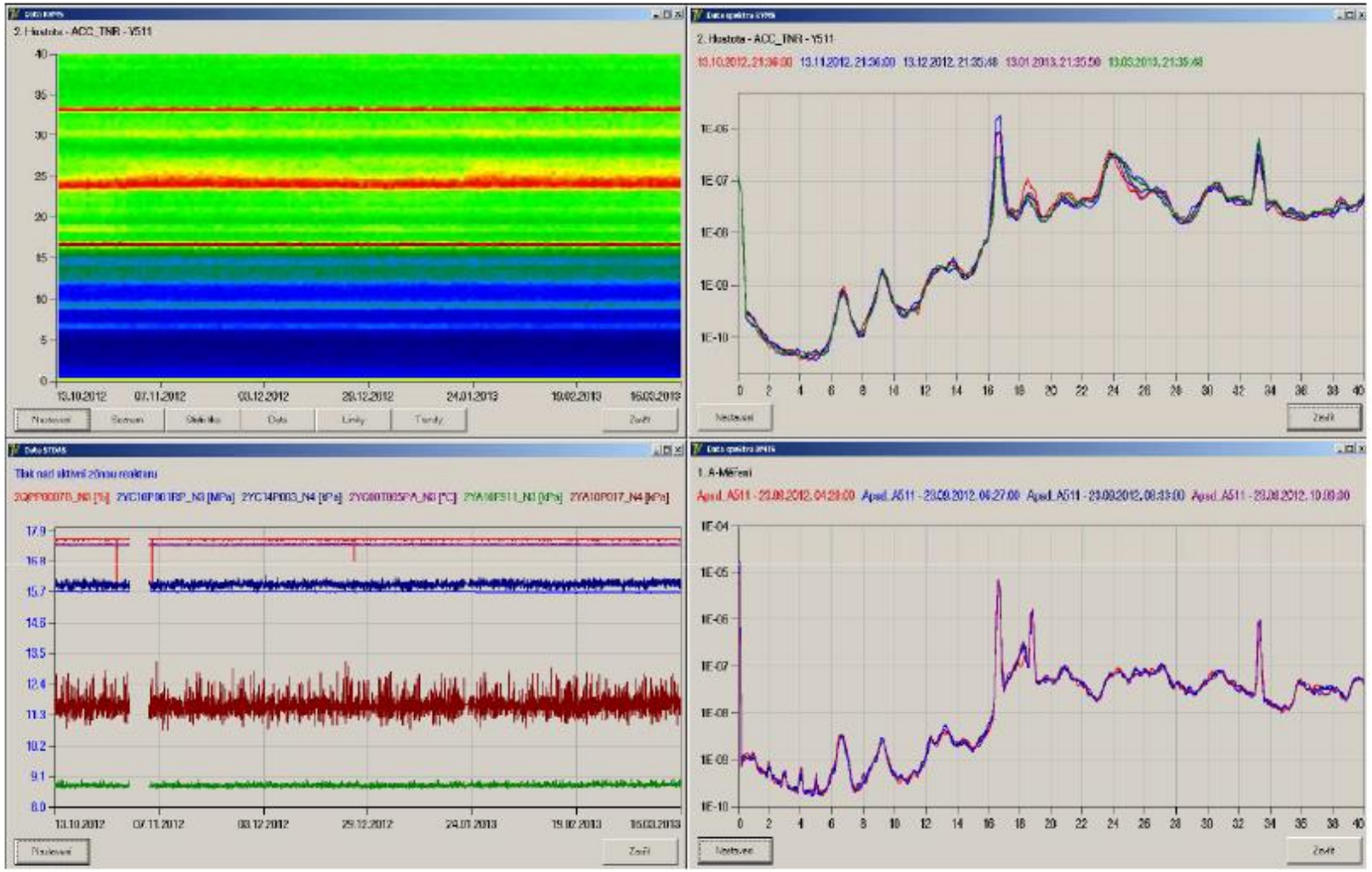
Data export

Administration of output result presentation

Tools

UIZ Unified information source

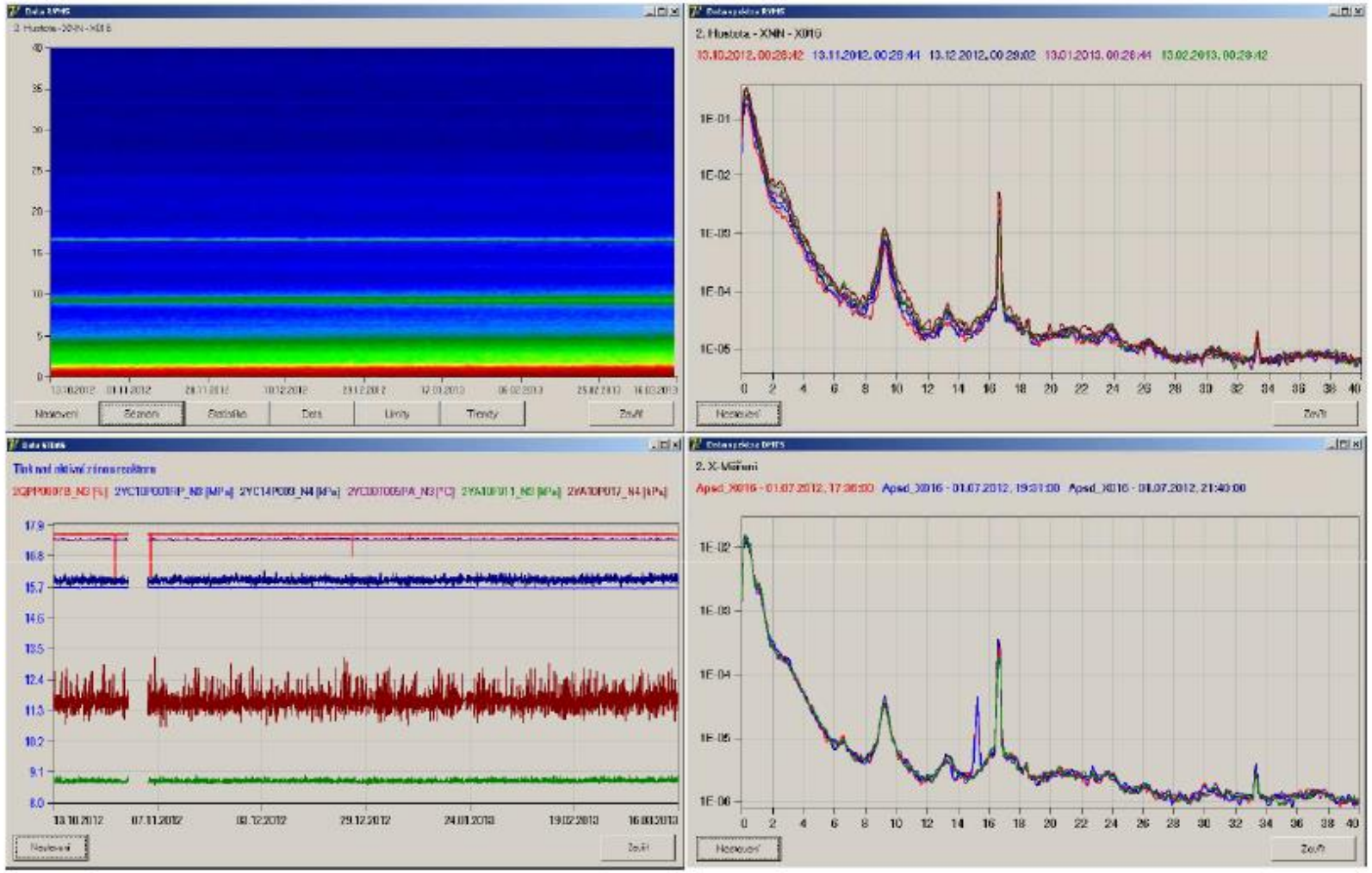
Accelerometer A511 Cycle U2C10



Tools

UIZ Unified information source

ExCore
X016
Cycle U2C10



Identification of reactor phenomena

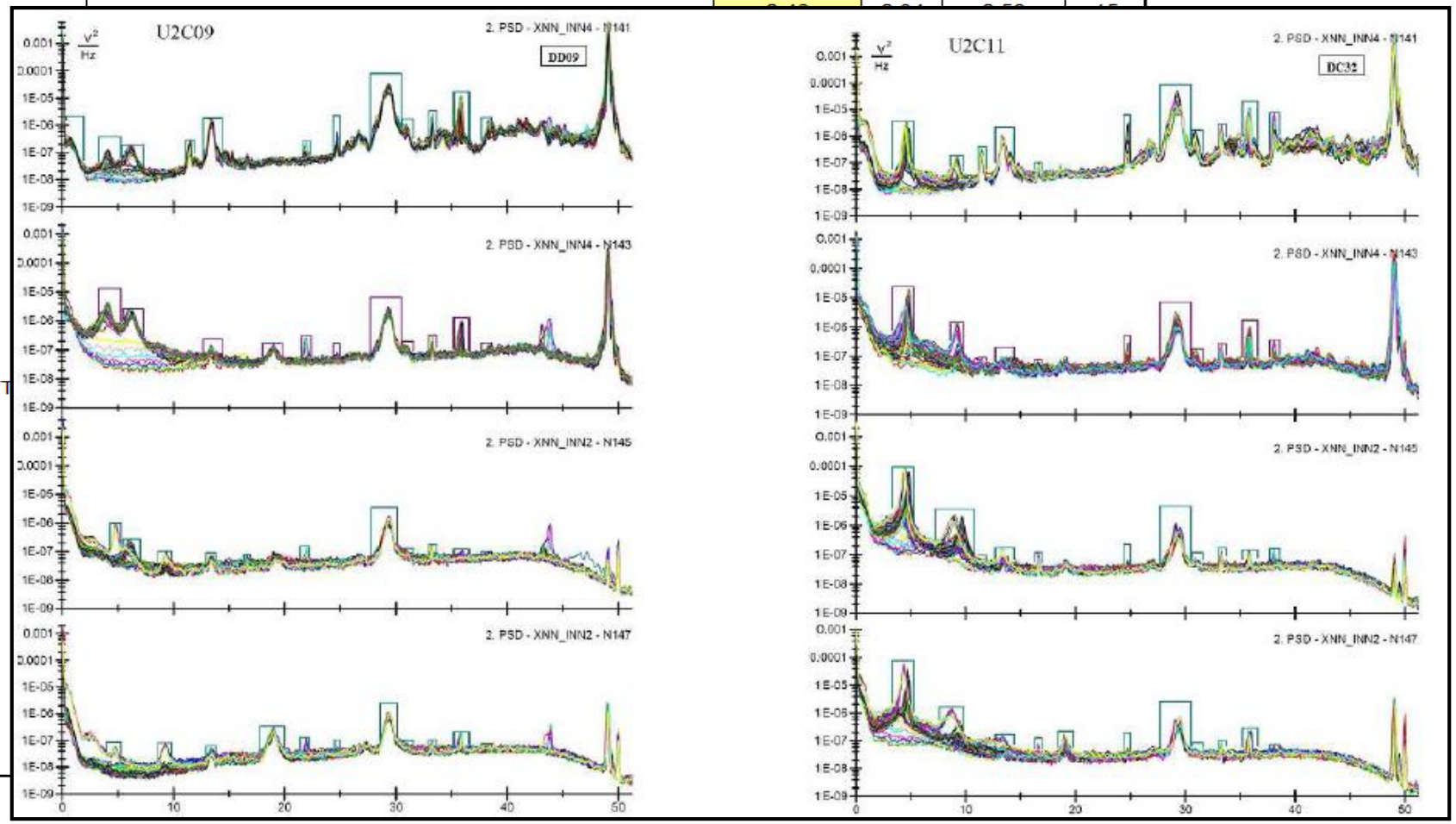
Reactor vibration phenomena were investigated on the base of results

- initial start-up measurements made by Skoda JS during commisioning of two units NPP Temelin
- mathematical models of reactor WWER1000/320 developed by West Bohemian University
- spectral masks from WWER 1000/320 designer Gidropress
- operational diagnostic measurements with Westinghouse VV6 and TVSA-T fuel

Identification of reactor phenomena

#	Komponenta	Palivo	Tvar kmitu	Frekvence	Pásma frekvencí D	Pásma frekvencí H	Zdroj	Snímače Acc	Snímače Xnn	Snímače Inn	Snímače Pft	Snímače Tcc	RVMS APSD	RVMS CPSD	RVMS Col+Quad	RVMS KonfigSoubory	DMTS / RVDT APSD	DMTS / RVDT CPSD	DMTS / RVDT Stat TD	DMTS / RVDT JTFS	DMTS / RVDT KonfigSoubory
7	TNR	TVSA-T																			
8																					
29	NV																				
30																					
46	PS																				
47																					
48																					
49																					
50																					
51																					
52	PP		10,11																		
53			13,14 ohyb																		
54			22,23																		
55			61,62 ohyb																		
58	TNR																				
59			Ve																		
60			K																		
61			Kývár																		
62																					
63			Ver																		
64	PS																				
65																					
66																					
67																					
68																					
69	PO		St																		
70																					
71			1.SV v TNR																		
72			1.SV v TNR																		
73																					
74																					
75																					
76																					
77			3/2 ultr																		

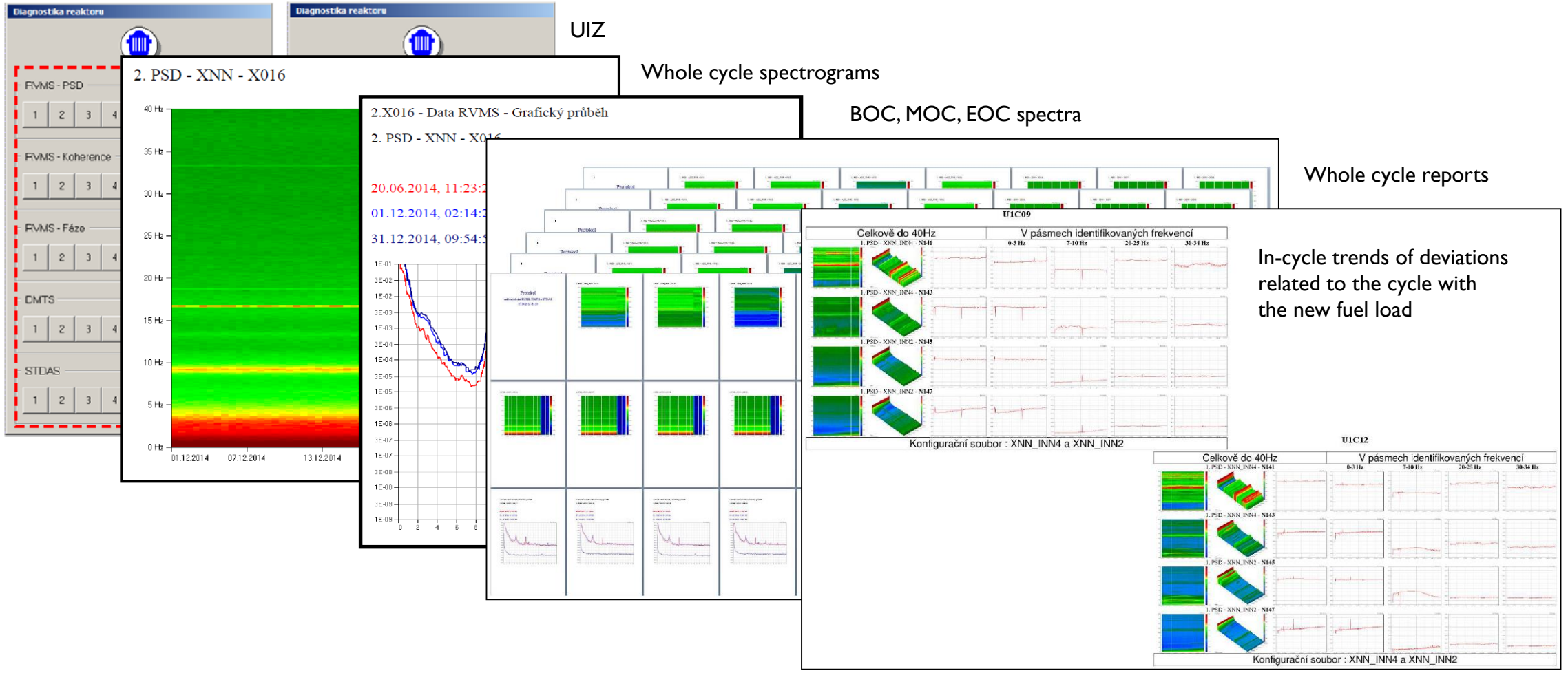
#	Komponenta	Palivo	Tvar kmitu	Frekvence	Pásma frekvencí D	Pásma frekvencí H	Zdroj
78	PS						
90	PS						
79	PS						
46	PS						
64	PS						
80	PS						
91	PS						
81	PS						
47	PS						
65	PS						
82	PS						
92	PS						
83	PS						
48	PS						
52	PP						
84	PS						
85	PS						
66	PS						
86	PS						
87	PS						
88	PS						
53	PP						
89	PS						
67	PS						
93	PS						
54	PP						
51	PS						
68	PS						
94	PS						
55	PP						
50	PS						
50	PS						



Noise analysis in processing of plant data

Scope of operational NPP noise diagnostics

Monitoring



UIZ

Whole cycle spectrograms

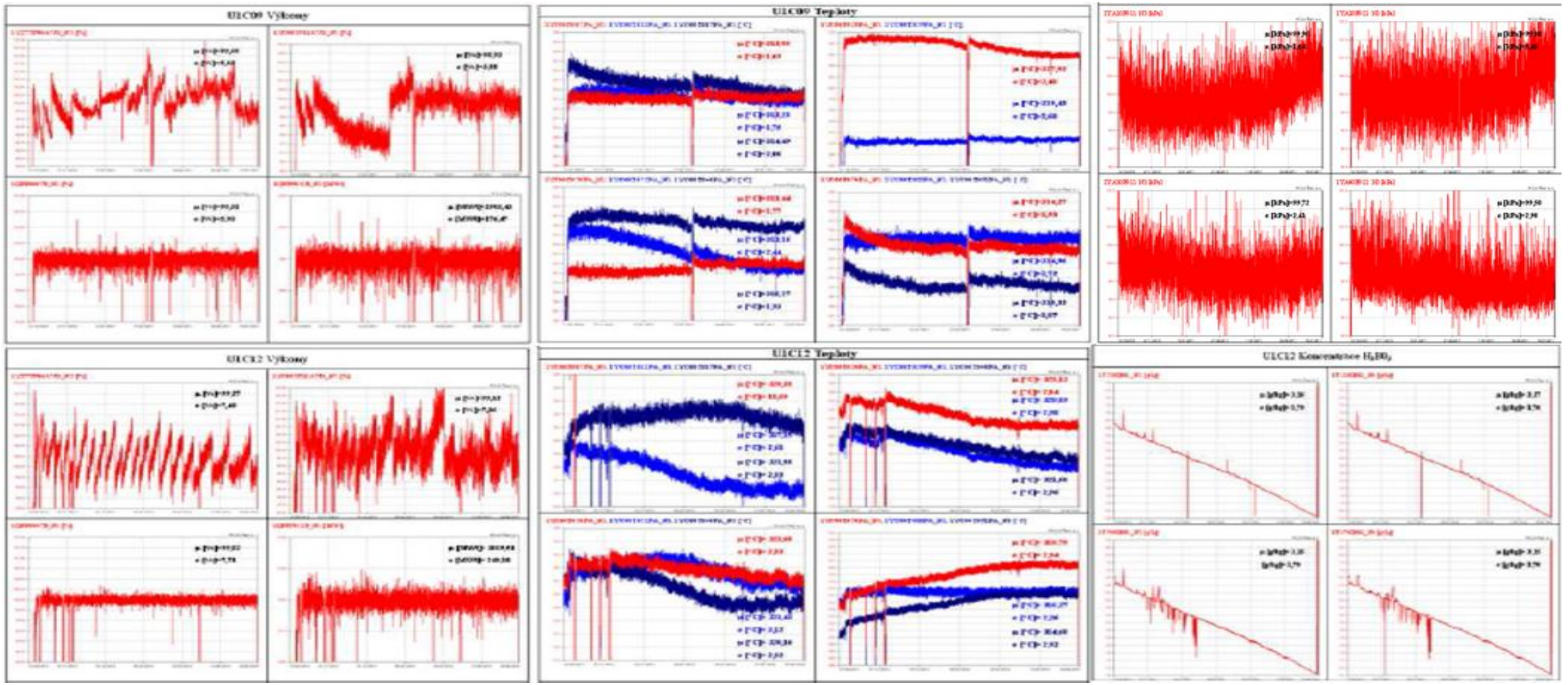
BOC, MOC, EOC spectra

Whole cycle reports

In-cycle trends of deviations related to the cycle with the new fuel load

Scope of operational NPP noise diagnostics

Technological parameters



Power

Temperature

Flow / H3BO3

Investigated tasks

Fuel rod infrigement

Beat effects

Fuel assemblies vibration

Linear stepper motor vibration

Incompatible rod insertion

Power tilt

Coherence maps

Investigated tasks

Unreleased and released VV6 fuel rod infrigement

Analysis of one possible reason of VV6 fuel rod integrity infringement was done in Skoda JS for Temelin U2C3 cycle by comparison of computed hydrodynamic forces acting on fuel rods with natural bending frequencies of fuel rods

Assumptions

- loss of contact between rod and grid in the area of spacer grids 2, 3, 4
- coolant flow with velocities which have characteristic values for a flow around fuel rods
- pulsation of hydrodynamic forces has a frequency in the range 1 – 9 Hz and acts primarily on the level of 1 – 4, 8, 9 spacer grid

Detailed measurements were made by system DMTS at N_{nom}= 100% with all working MCPs during Temelin U1C3 and U2C3 cycles

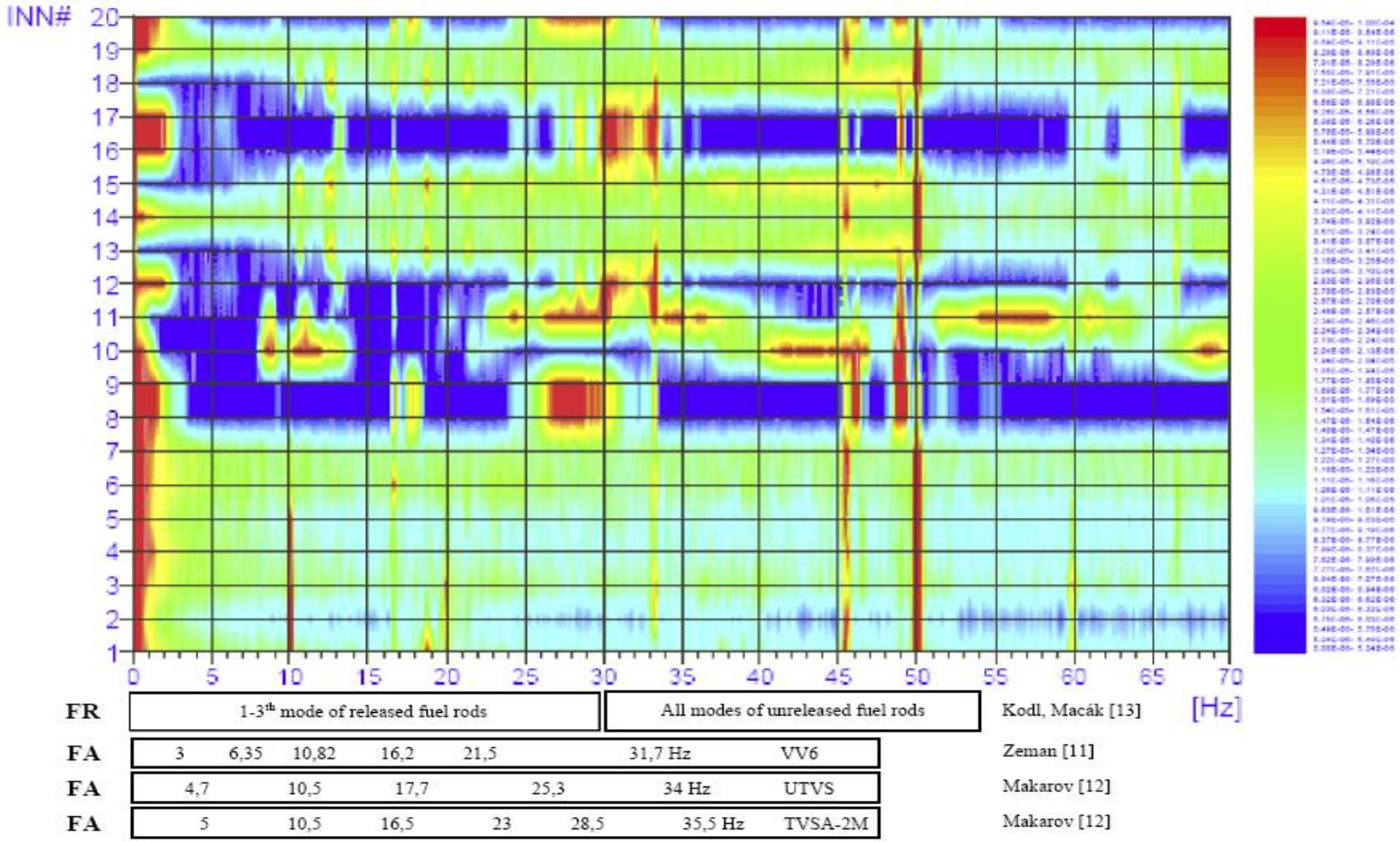
Processing of acquired measurements was done in spectral maps

- acquired data of 15 min unified length were centred, normalized to maximum value and processed in time and frequency domain
- 52 SPND from altogether 272 measured ones were chosen for further evaluation with respect to basic statistical descriptors
- frequency interval 0 – 70 Hz for processing was determined to see overall PSD distribution of unreleased and released rods

Investigated tasks

Unreleased and released VV6 fuel rod infrigement

U1C03

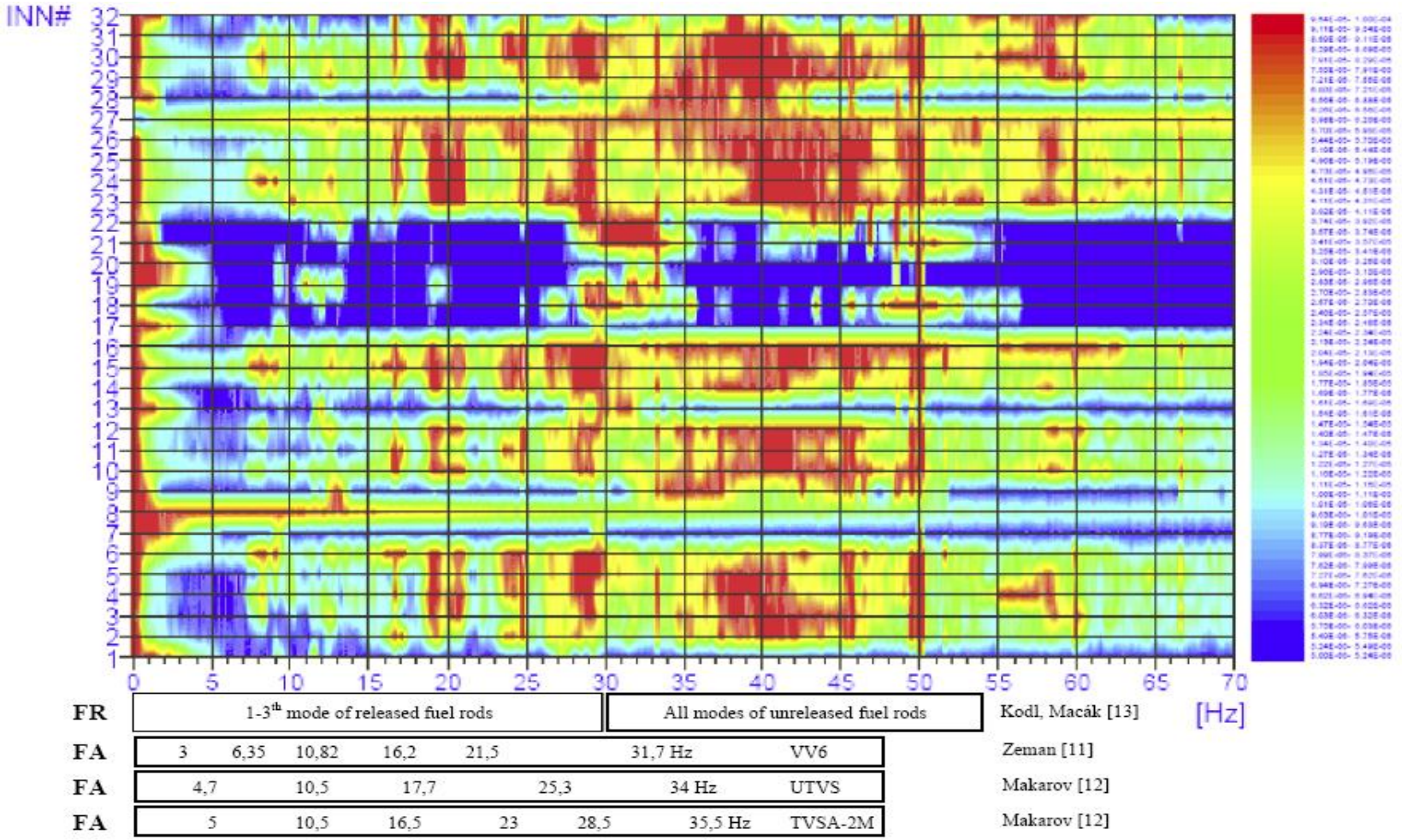


Spectral maps are 3D graphs in XY view with arbitrary variables (frequency and spectra serial number) and PSD value as dependent variable Z

Investigated tasks

Unreleased and released VV6 fuel rod infrigement

U2C03



Spectral maps yield overall and quick overview in the case when comparison between units is required (original required aim of the work)

Investigated tasks

Unreleased and released VV6 fuel rod infrigement

COMMENTS

The operational data from selected self power neutron detectors of both NPP Temelin units were processed together with modal parameters of VV6 and TVSA assemblies to show probable region of possible fuel rod infringement.

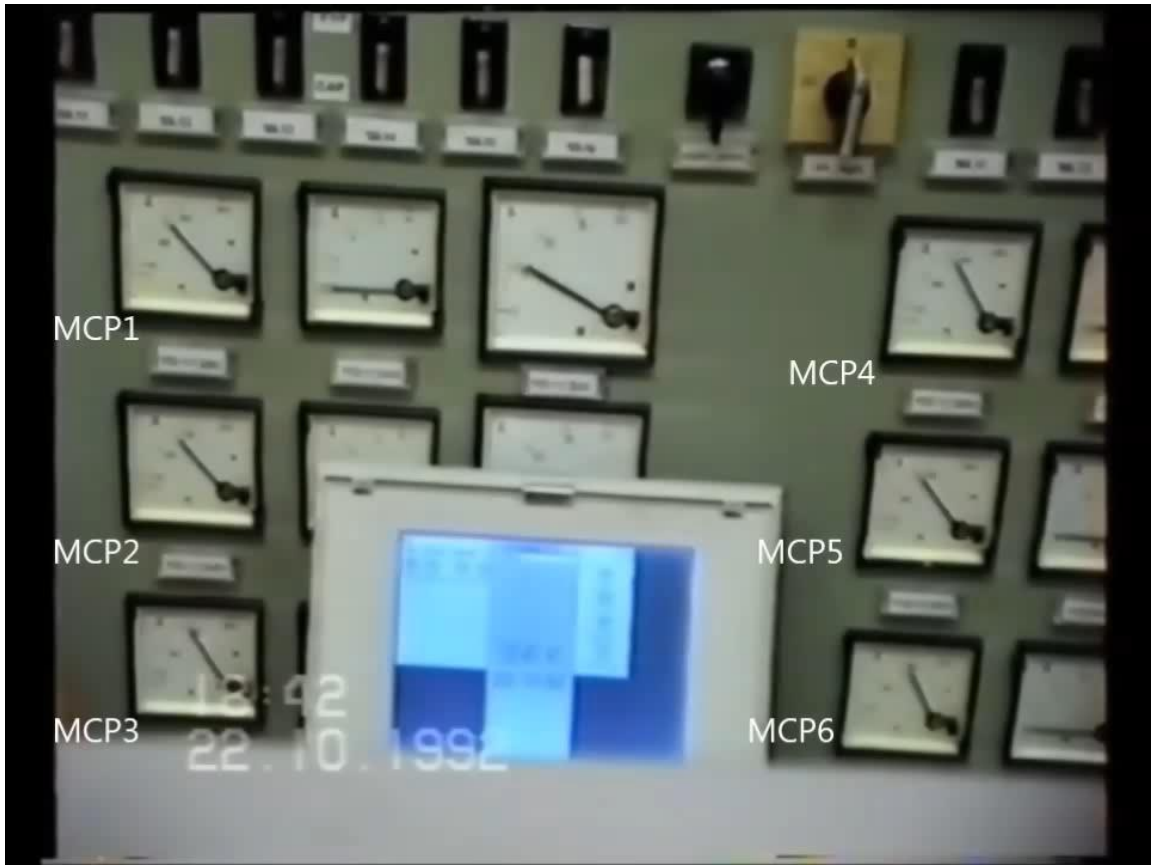
- peak frequencies and amplitudes occurrence of both units with VV6 fuel basic design in the same fuel cycle is distinctively different
- the 2nd unit amplitudes are almost ten times higher with the significant occurrence number also in the region of 1 – 3rd mode released fuel rods natural frequencies
- there are however frequency individual values, smaller or larger regions where the both units behave in similar manner
  - neighbourhood of 9 and 13 Hz
  - revolution frequency 16,6 Hz and its harmonic 33,3 Hz
  - neighbourhood of 18 Hz
  - bands of 25 – 30, 30 – 32, 41 – 47 and 49 – 50 Hz
- conclusions are valid only for the one cycle of units 1 and 2
- more detailed approach is required in the future for qualified fuel rod infringement detection

Investigated tasks

Beat effects

NPP Dukovany : U4C05 unusual reactor dynamic behaviour

Operational measurement : Unit 4, 22.10.1992



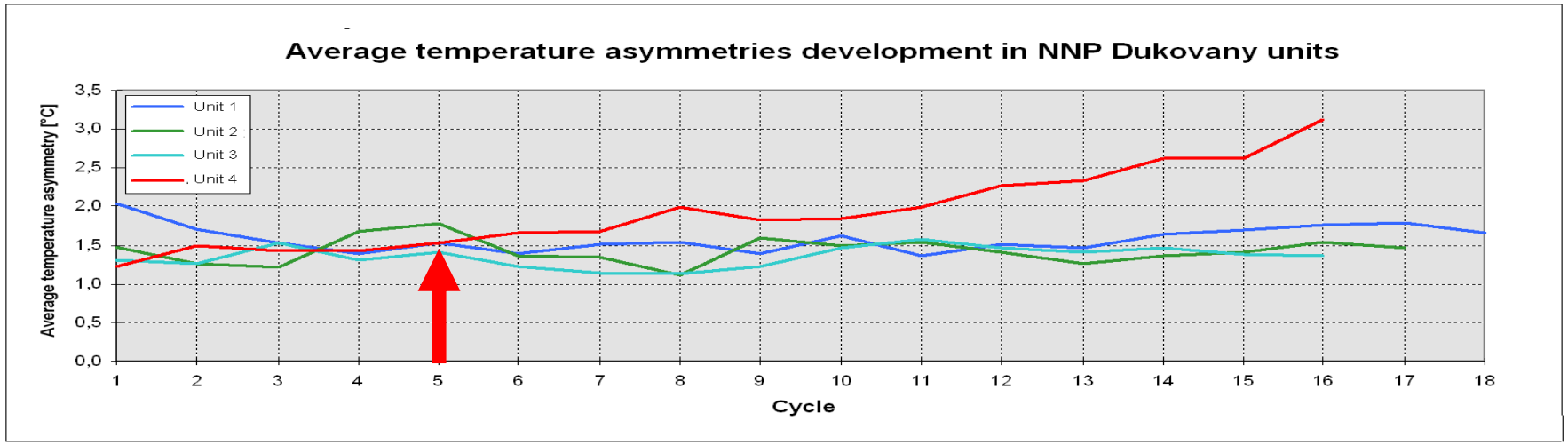
Control panel of MCP supply current

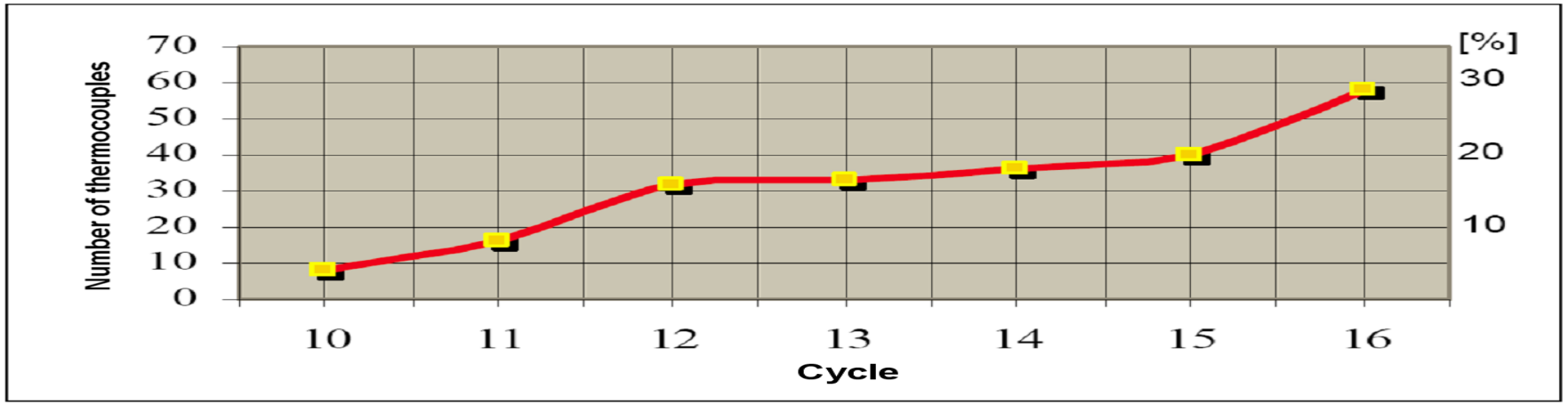
30A amplitude swing instead of usual 3-5A in 150A range

Investigated tasks

Beat effects

Consequences





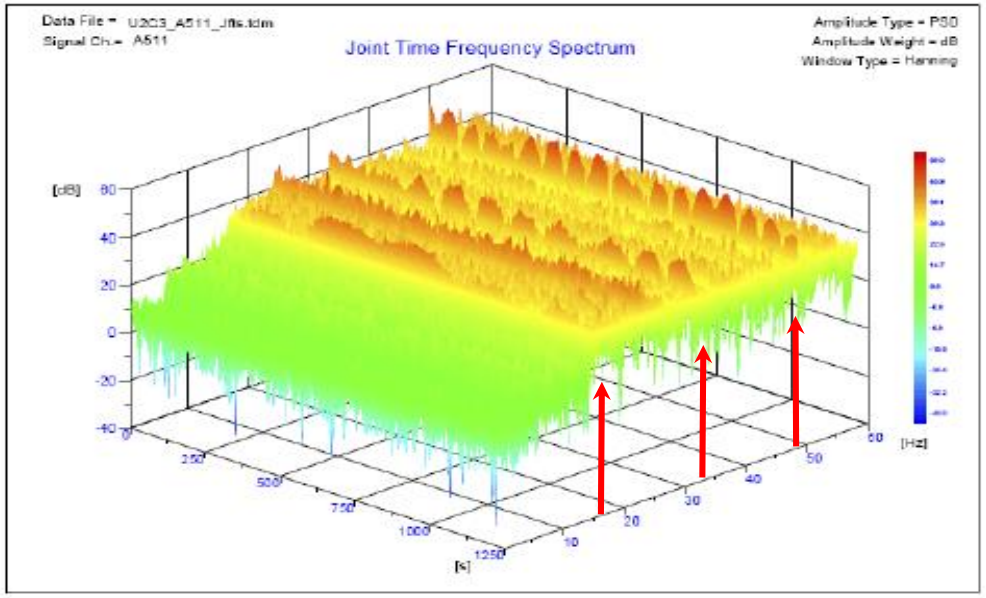
Investigated tasks

Beat effects

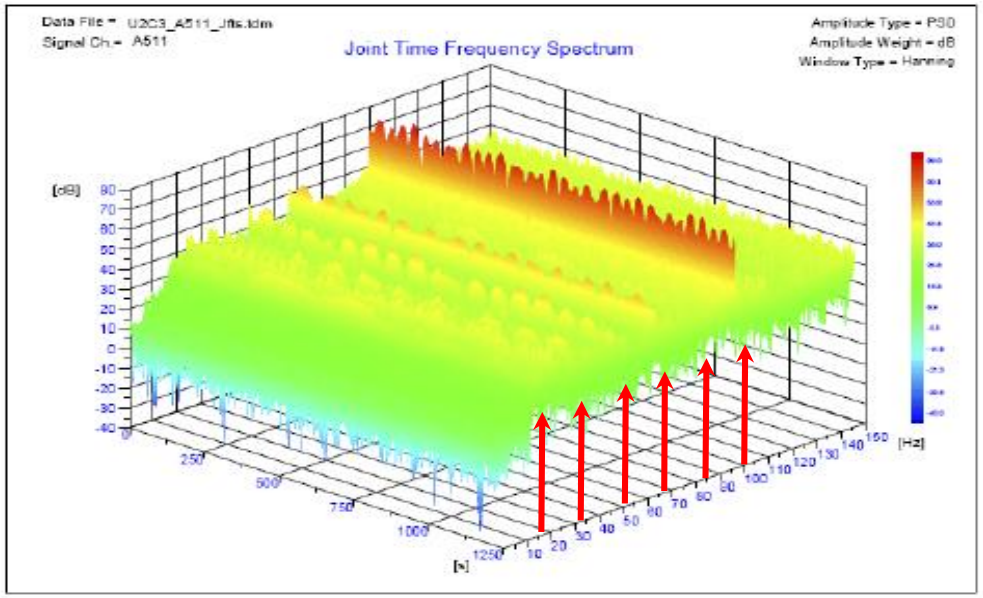
JTFS spectrograms of reactor head accelerometers (NPP Temelin, N_{nom} =100%)

For the purpose of reactor vibration diagnostics MCP revolutions were in the past more or less considered to be stable.

It was proved that slightly differed revolutions cause beat vibrations at MCP revolution harmonics. JTFS spectrograms confirm this reality in joint frequency time domain.



0 – 50 Hz

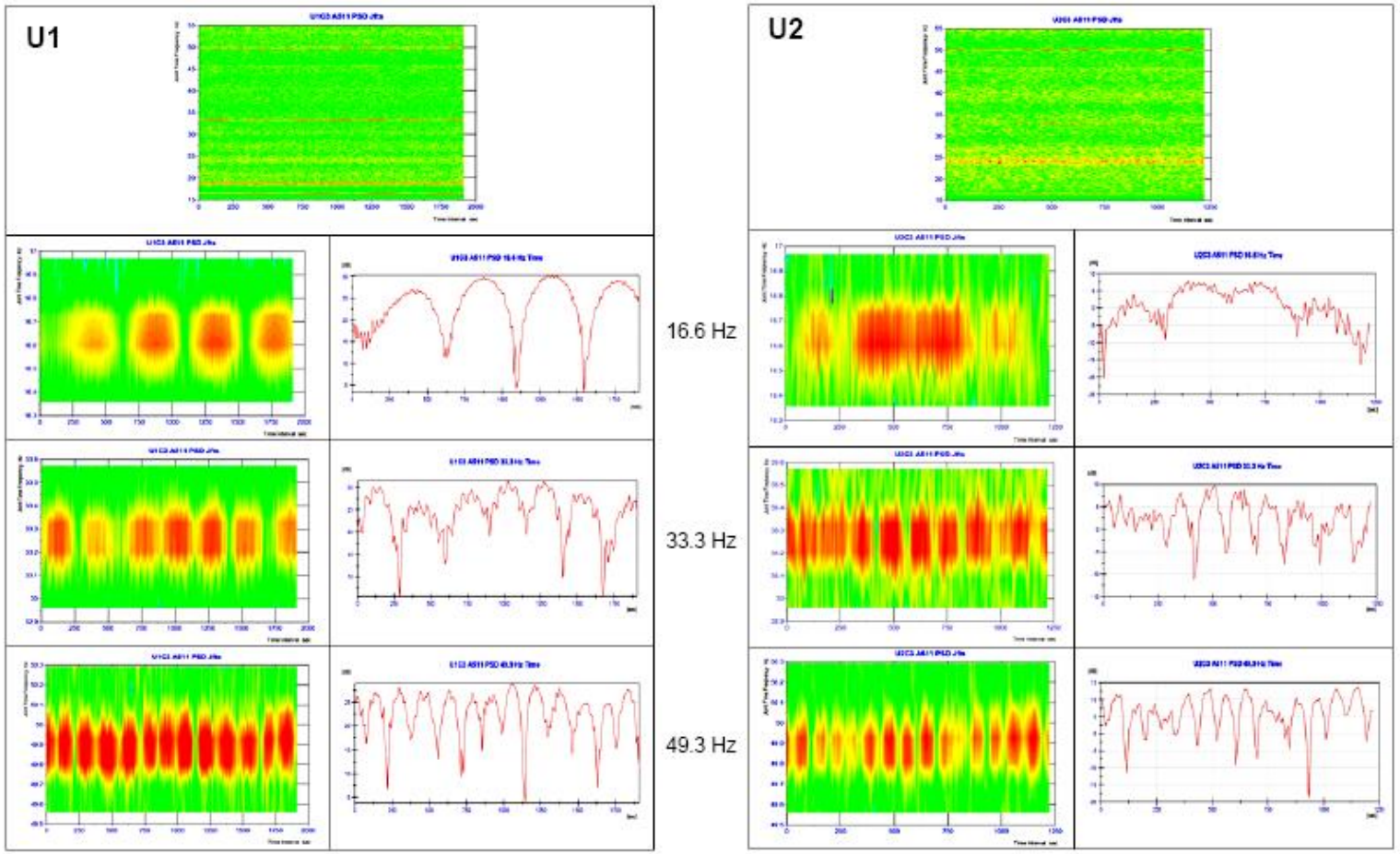


0 – 150 Hz

Investigated tasks

Beat effects

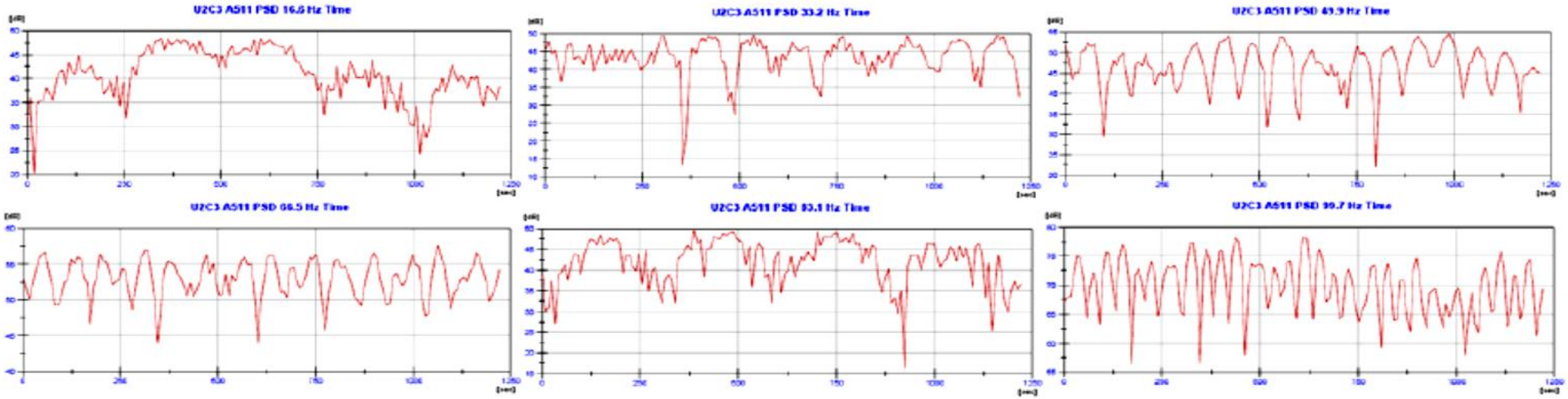
JTFS spectrograms of reactor head accelerometers (NPP Temelin, N_{nom} =100%): 16.6, 33.3, 49,3 Hz



Investigated tasks

Beat effects

Statistics of beat MCP harmonics (A511 JTFS spectrogram U2C3



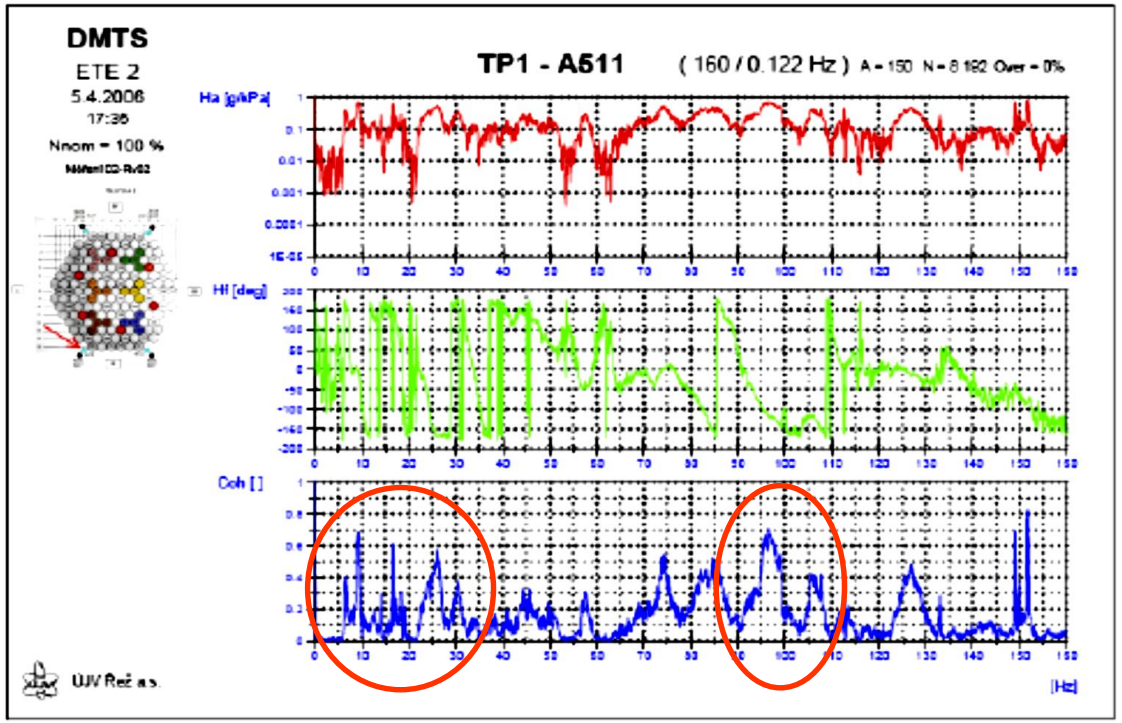
MCP Beat Harmonics [Hz]	[dB]				
	Average	StandDev	Min	Max	Range
16,602	40,8	5,2	20,3	48,5	28,2
33,204	43,5	5,1	13,1	49,6	32,3
• 49,926	46,6	5,2	22,2	54,4	36,5
66,528	53,0	2,6	43,9	57,6	13,7
• 83,130	41,9	5,7	16,2	49,7	33,4
•••99,730	69,7	4,8	56,3	78,2	21,9

Dominant beat harmonics by statistical descriptors : 99,730 Hz, 83,130 Hz, 49,926 Hz.

Investigated tasks

Beat effects

Transfer function of input/output pressure pulsations TP1/TP5 and A511

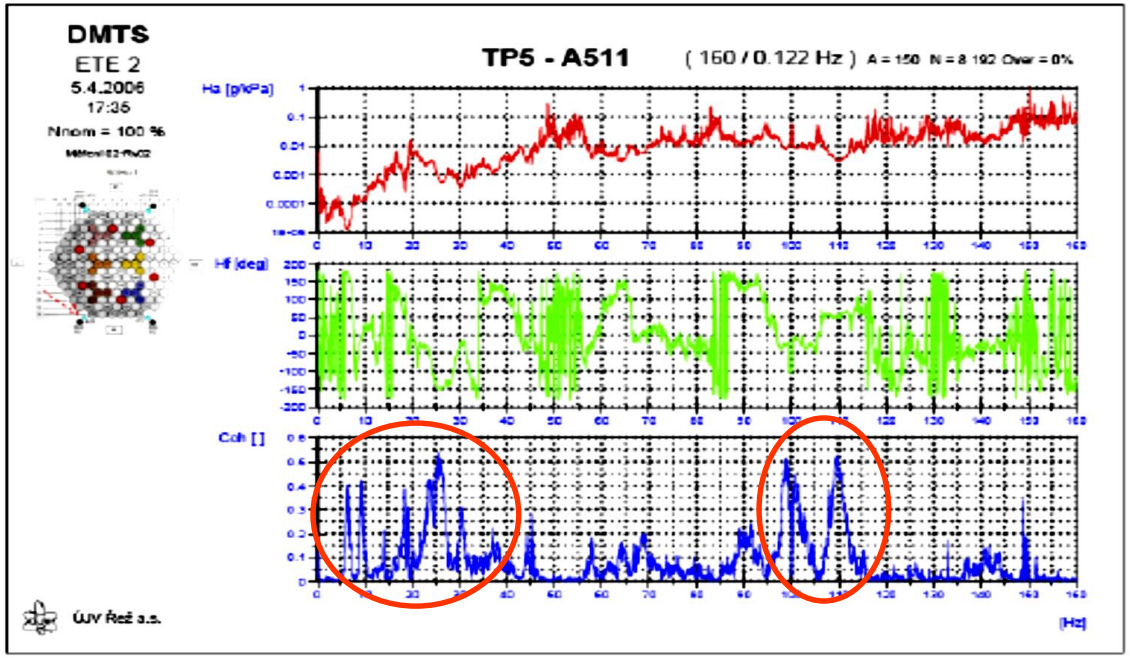


Transfer Function Amplitude, Phase and Coherence

Reactor input pressure pulsation TP1

Reactor head vibration A511

Reactor output pressure pulsation TP5



Reactor head vibrations are in good coherence with pressure pulsations in frequency regions up to 30 Hz and around 100 Hz

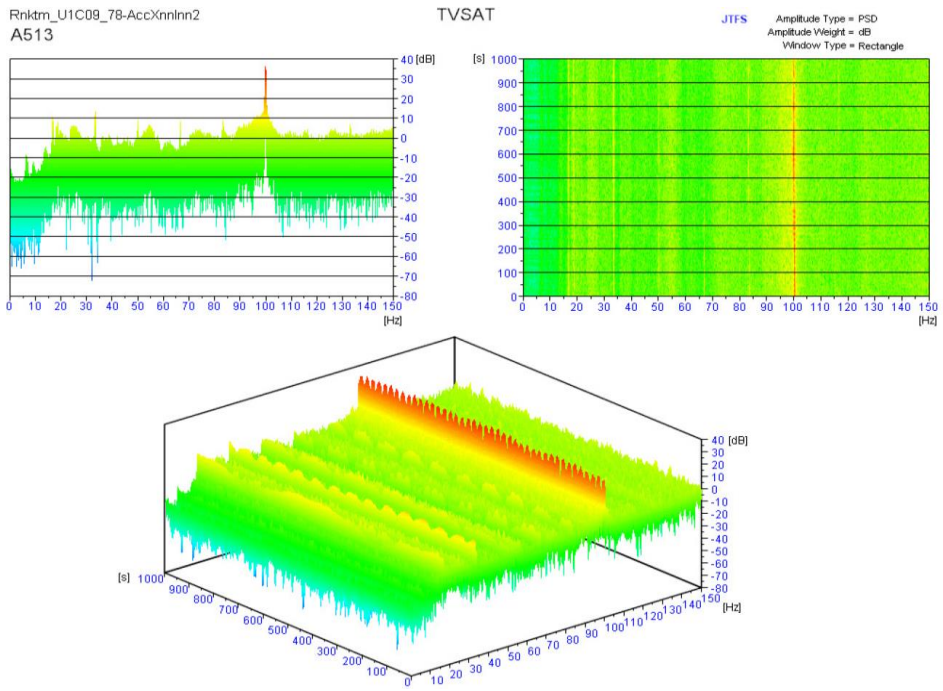
Investigated tasks

Beat effects

Pressure vessel and core responses

Reactor head accelerometrs

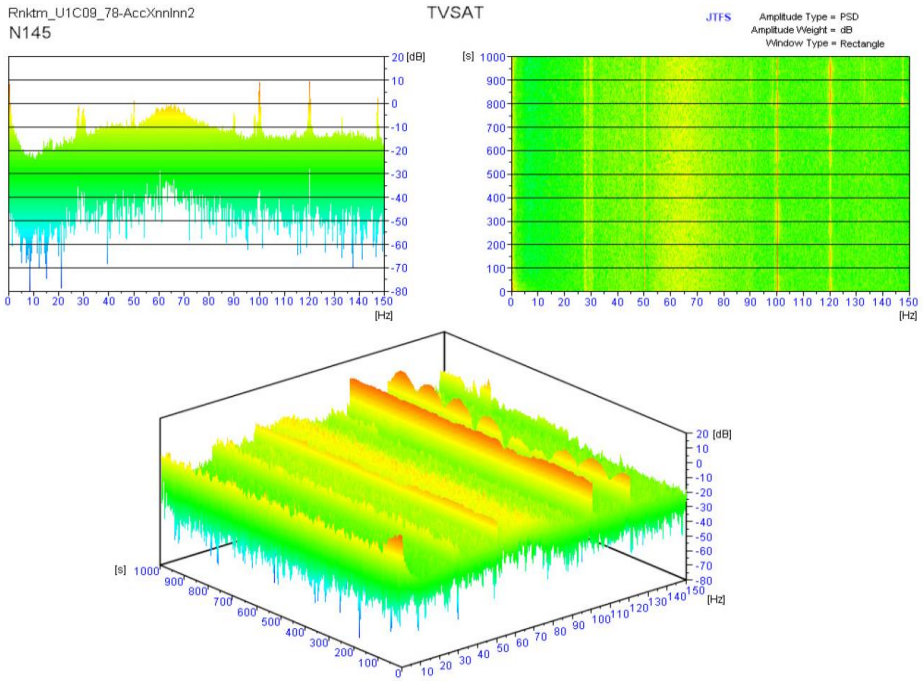
U1C09
A513



Reactor vessel movement

In-core SPND‘s

U1C09
N145

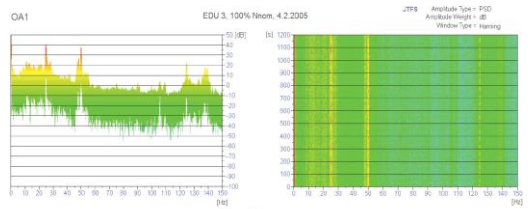


Reactor fuel and internals behaviour

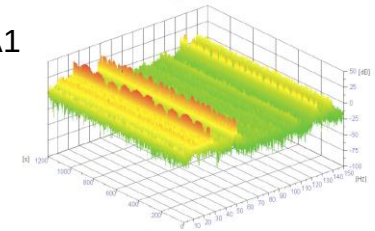
Investigated tasks

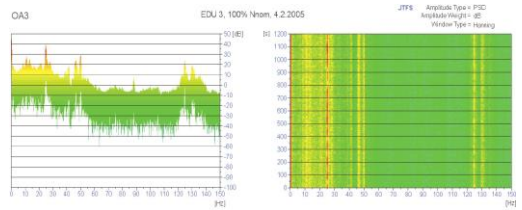
Beat effects

NPP Dukovany: Reactor head absolute displacement sensors

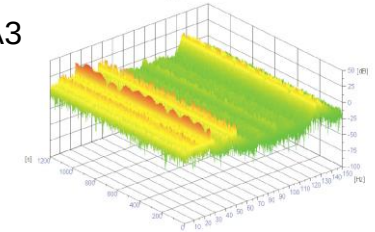


OA1



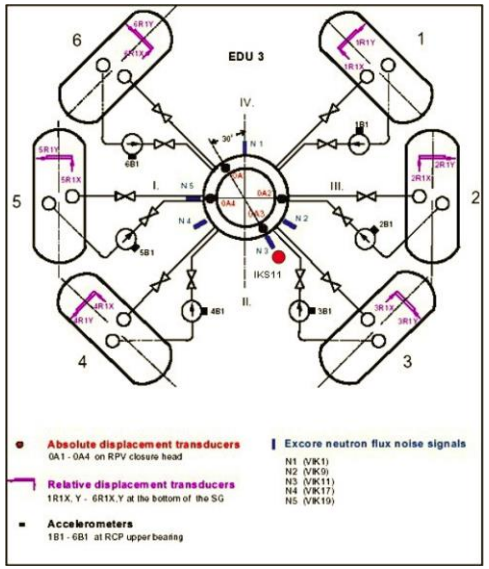


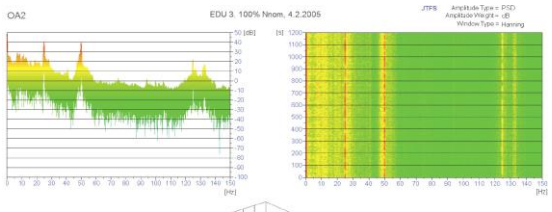
OA3



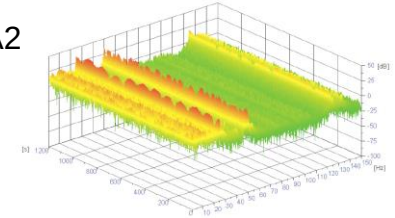
EDU3

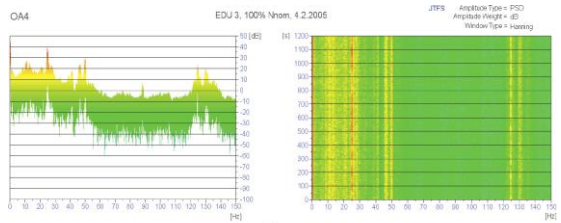
U3C18



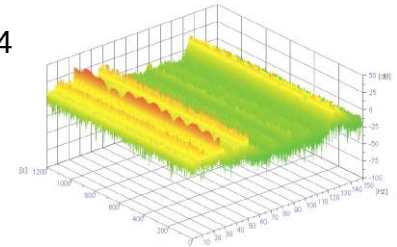


OA2





OA4



Pressure vessel dominant beat frequencies at MCP 1st and 2nd revolution harmonics : 24Hz, 48Hz

Investigated tasks

Beat effects

COMMENTS

Historical operational experience of NPP Dukovany was demonstrated with its important operational consequences.

Vibration beats of pressure vessel and fuel assemblies namely on main circulation pump revolution harmonics were referred to pressure and flow fluctuations generated by main circulation pumps with slightly differed revolutions.

Beat vibration effects of NPP Temelin and Dukovany were shown to be common feature of dynamic pressure vessel and core behaviour.

MCP harmonic frequencies were shown to be dominating with beat character representing inconsiderable component in overall reactor vibration, which may cause contact loss of internal parts during long-term operation.

It is advisable to extend synchronous measurement and processing to other diagnostic sensors inclusive main circulating pumps parameters in order to be able detecting incorrect behaviour during the reactor operation.

CONCLUSIONS

In this contribution we introduced

- sources of real plant data covering sensors of reactor movement, ex- and in-core neutron flux
- database tool containing diagnostic and technological quantities for subsequent analyses in time, frequency and joint time-frequency-domains
- the process of reactor phenomena identification which the scope of operational noise diagnostics is based on
- investigated tasks - namely the cases of fuel rod infrigement and all round reactor beat effects.

We hope that by our participation in the Cortex project we shall be able to extend our solutions in the future.

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Thank you for attention!