Joint Institute for Nuclear Research
Frank Laboratory of Neutron Physics



MATHEMATICAL MODELING AND COMPUTATIONAL PHYSICS 2026

Analysis of the resonant properties of the IBR-2M reactor during a cycle using the basic elements method

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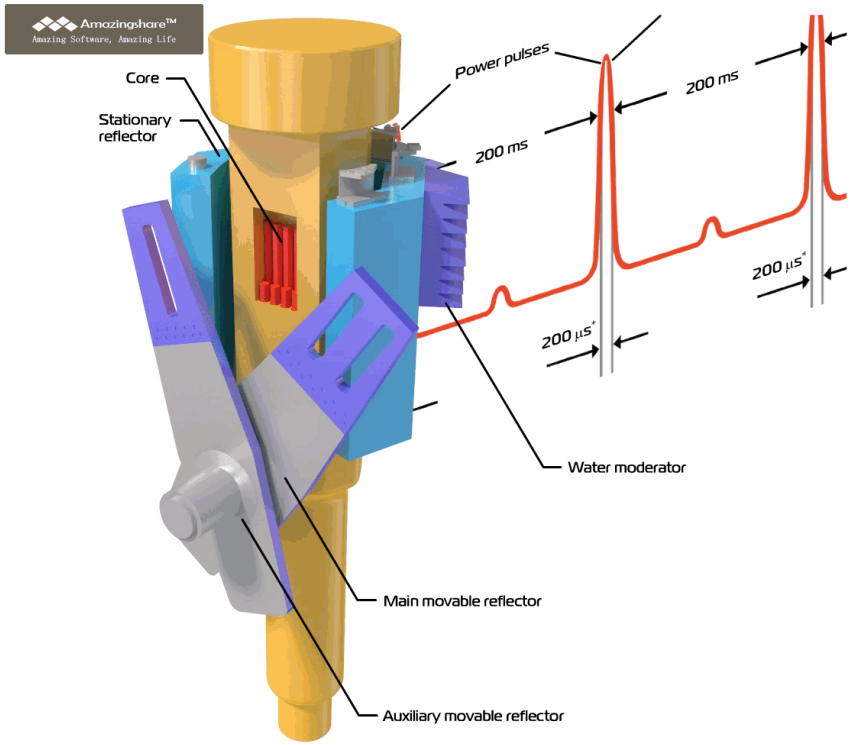
IBR-2M Pulsed Reactor: Key Features



Principle of Operation:

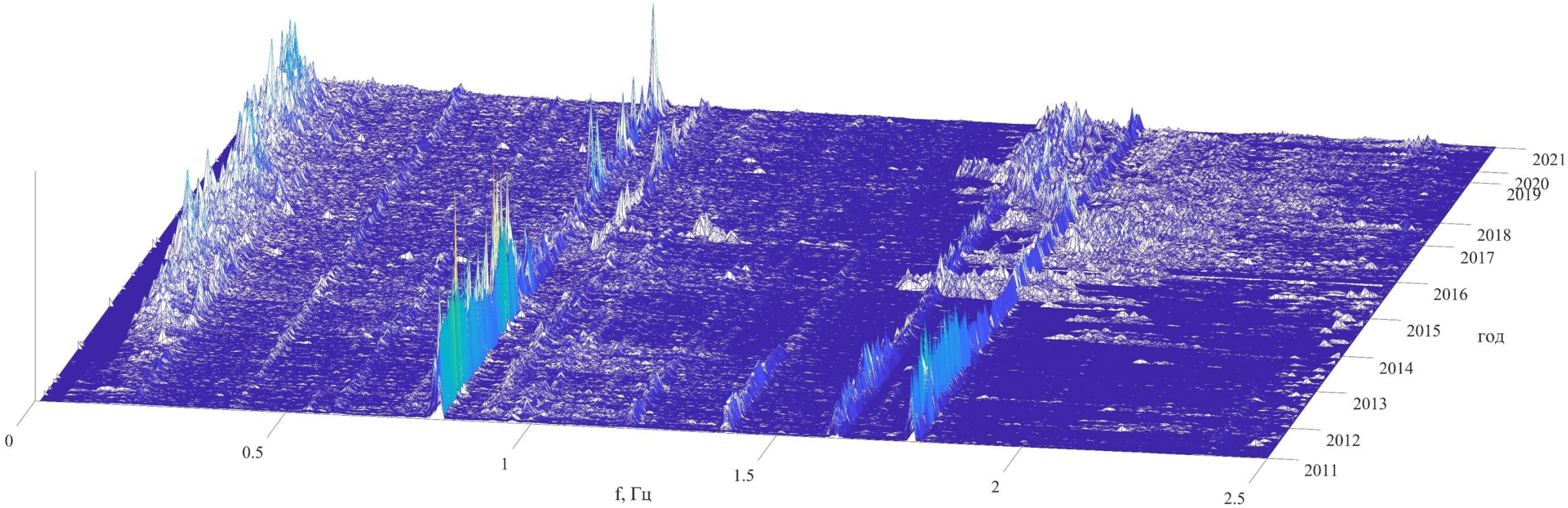
- Rotating reflectors create short supercritical bursts.
- Generates 200 μs wide neutron pulses every 0.2 s (5 Hz).
- 92% of energy released during the pulse.

http://flnph.jinr.ru/en/facilities/ibr-2

IBR-2M REACTOR PARAMETERS

Average power, MW	2
Fuel	PuO_2
Number of fuel assemblies	69
Pulse repetition rate, Hz	5
Pulse half-width, μs:	
fast neutrons	200
thermal neutrons	340
Rotation rate, rev/min:	
main reflector	600
auxiliary reflector	300
MMR and AMR material	nickel + steel
Thermal neutron flux density from moderator surface:	
- time average	~ 10^{13} n/cm^2·s
- burst maximum	~ 10^{16} n/cm^2·s

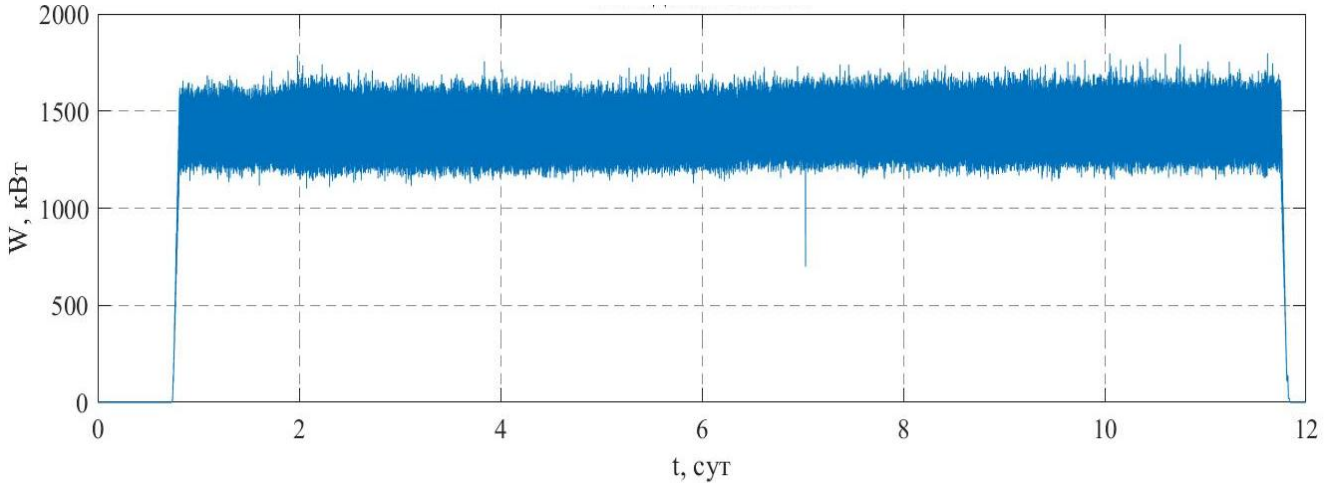
Spectral density of energy pulse of the IBR-2M: 2011-2021



Method

- SPECTRAL ANALYSIS
  - Pulse energy time series: up to $6 \cdot 10^6$ values per cycle
  - Segmentation into 4096-point blocks
  - Discrete Fourier transform (periodograms)
  - Normalization and decomposition:

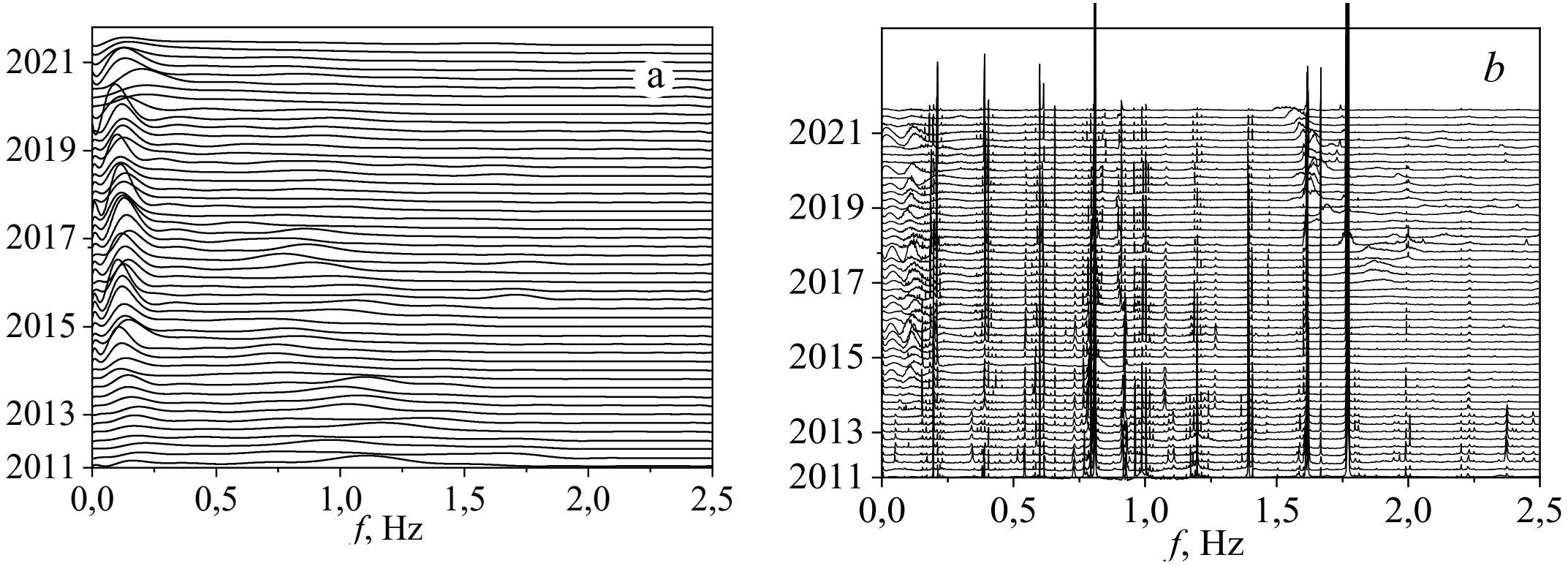
$$S(f) = S_{\text{bas}}(f) + S_{\text{lin}}(f)$$



- BASIC ELEMENT METHODS
  - Baseline is nonlinear → high-degree polynomials required
  - Ill-conditioning problem → BEM polynomials
  - Approximation as a “matryoshka”:

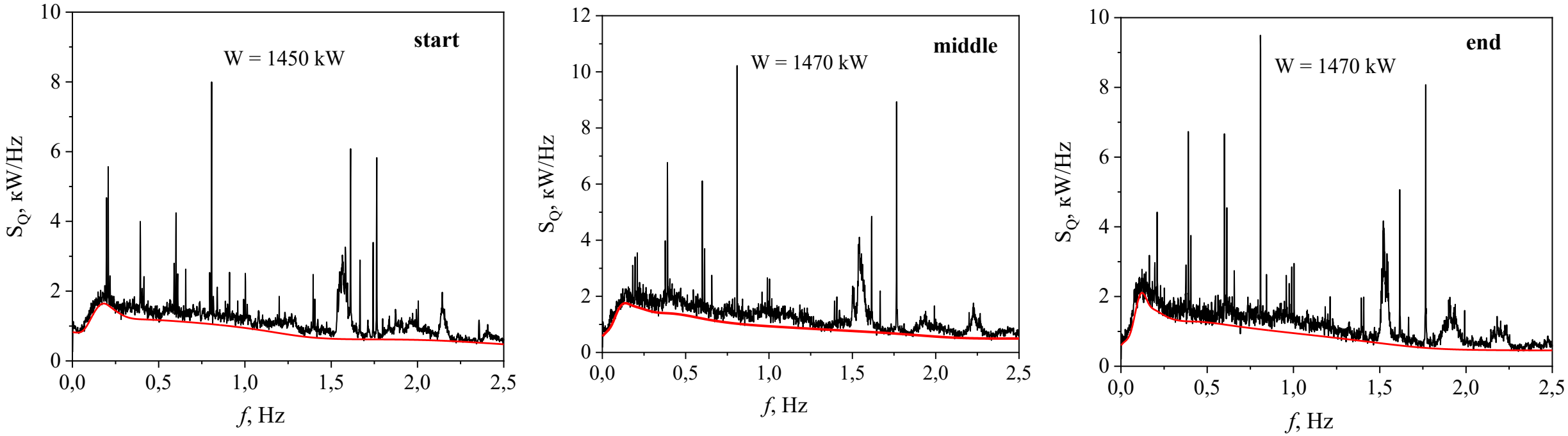
$$P_{BL} = \Pi_0 + Q(\Pi_1 + Q(\Pi_2 + \ldots + Q\Pi_m))\ldots)$$

Basic Elements Method (BEM)



Change in the baselines (a) and the line spectrum (b) in the pulse energy oscillations of the IBR-2M reactor over the entire operating period from 2011 to 2021 (before the reactor shutdown for equipment replacement)

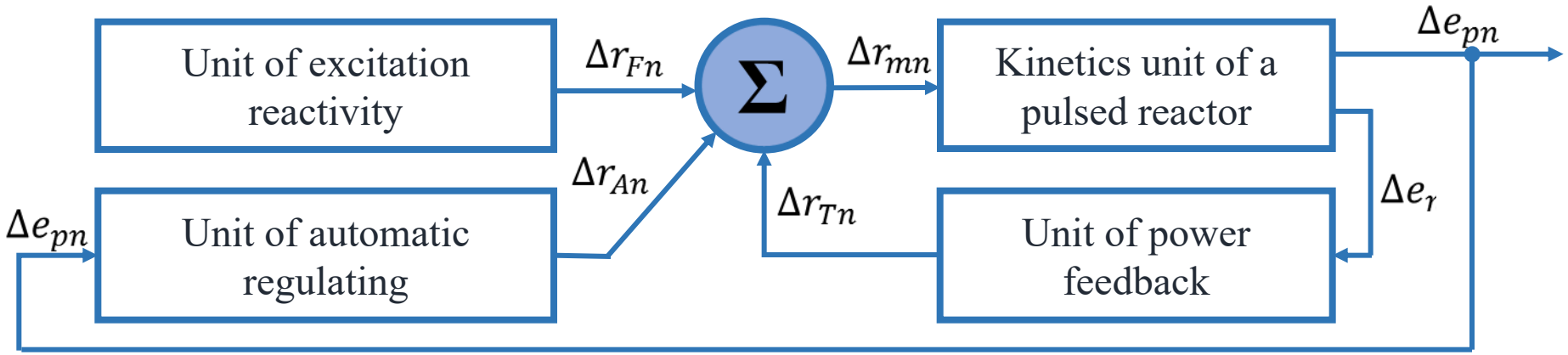
Basic Elements Method (BEM)



Power fluctuation spectral density (S_Q) of the IBR-2M reactor averaged over the start (April 15), middle (April 21), and end (April 25) of cycle No. 3, 2025, at average power level of 1450 kW, with a sodium flow rate through the core of 96-98 m³/h. f – frequency.

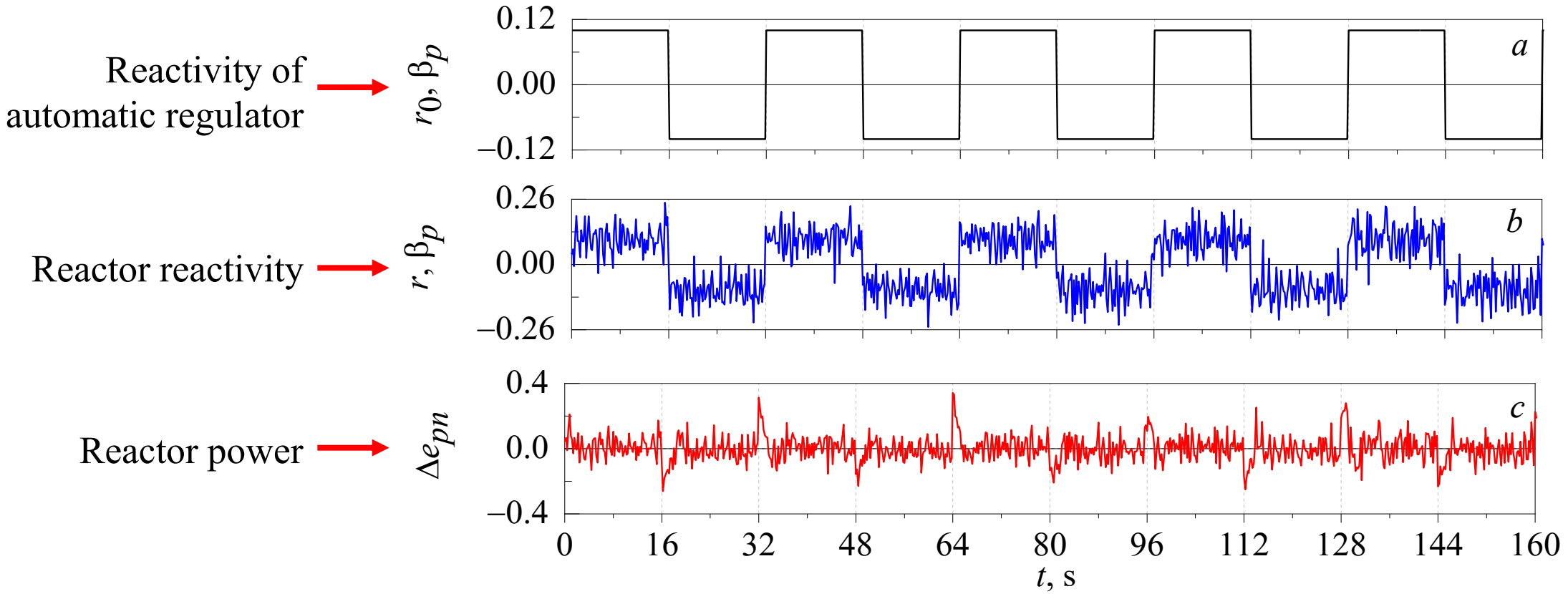
IBR-2M Reactor Dynamics Model

- A mathematical model was developed to simulate transients and frequency response.
- Three main modules:
  1. Kinetics
  2. Power Feedback (PF) due to reactor warm-up
  3. Automatic Regulator (AR)



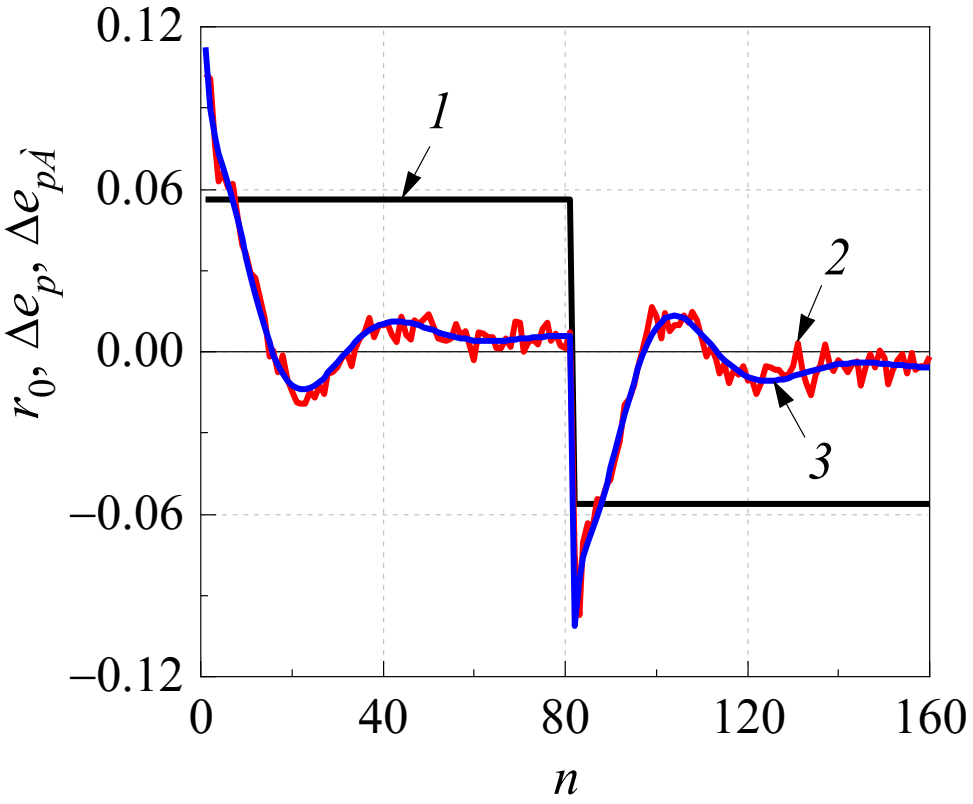
Block-scheme of the IBR-2M reactor with automatic regulating

Square oscillation of the reactivity for estimation of power feedback



Reactivity AR r_0 as a square wave with amplitude $0.1\beta_p$ and period 32 s (a), total reactivity with noise r (b) and relative deviation of the power pulse energy Δe_{pn} (c)

Approximation of power transient processes



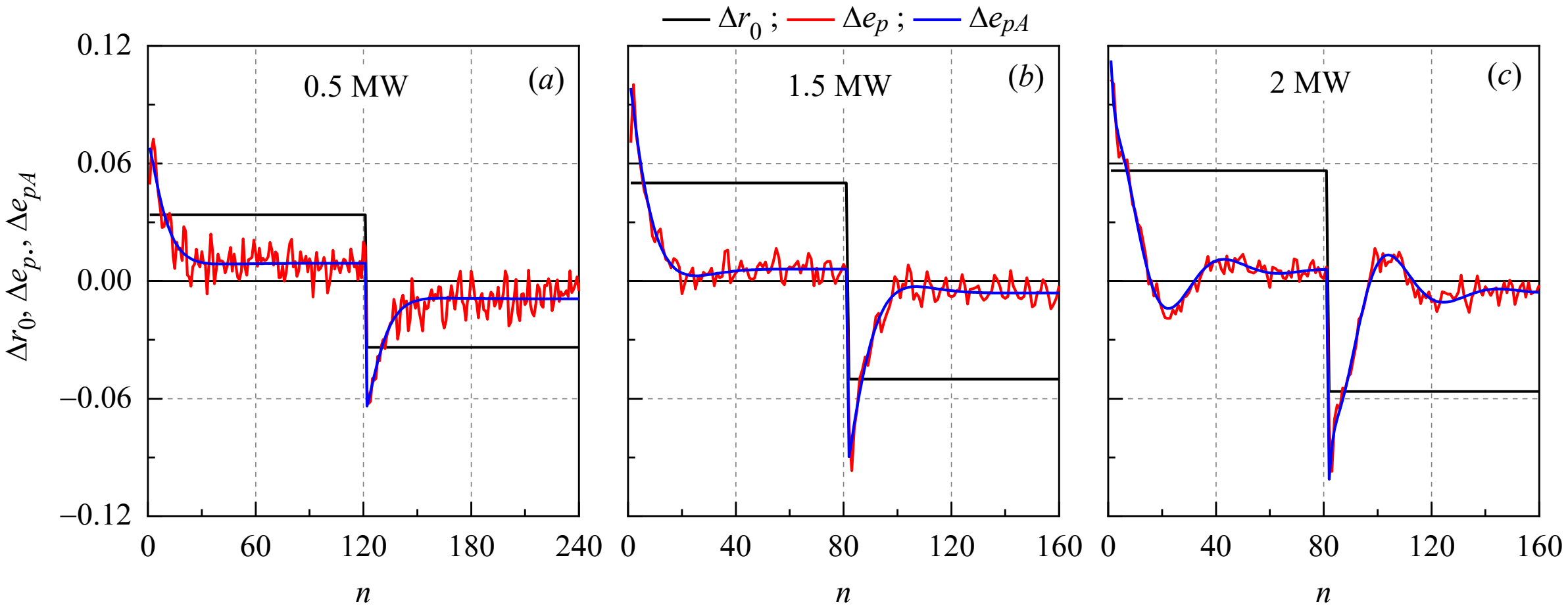
Transient processes caused by square oscillation **reactivity Δr_0, β_p (*1*)** of the IBR-2M reactor at average power of 2 MW (2015).

Δe_p – the deviation of the energy power pulse:

***2* – experimentally** and ***3* – modeling approximation**,

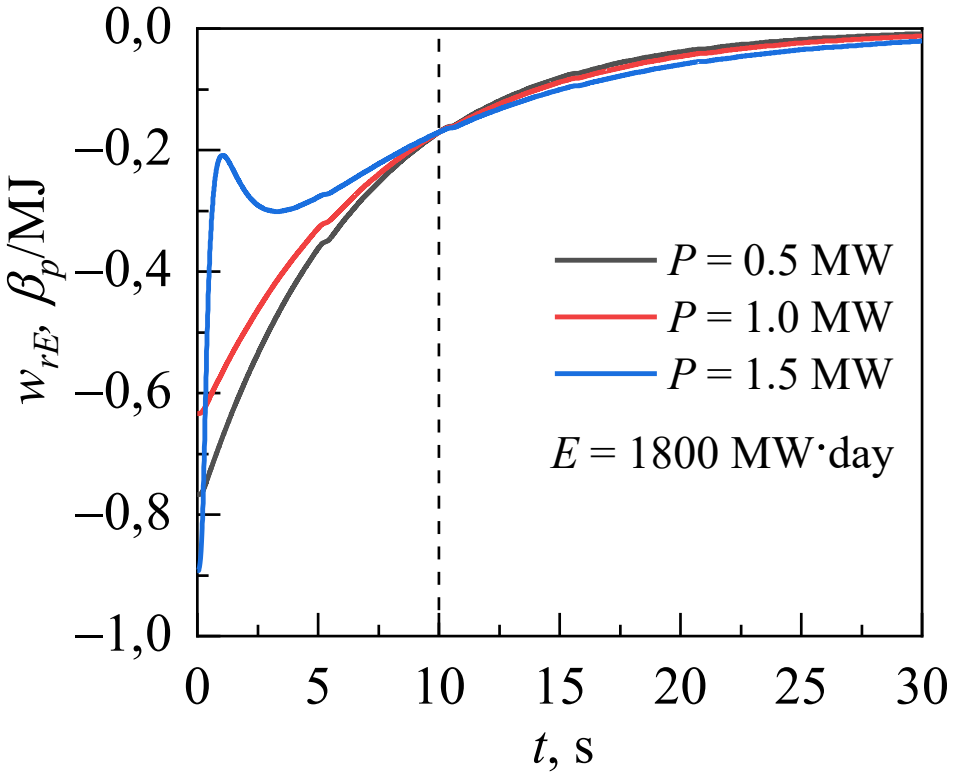
n – number of power pulses

Approximation of power transient processes



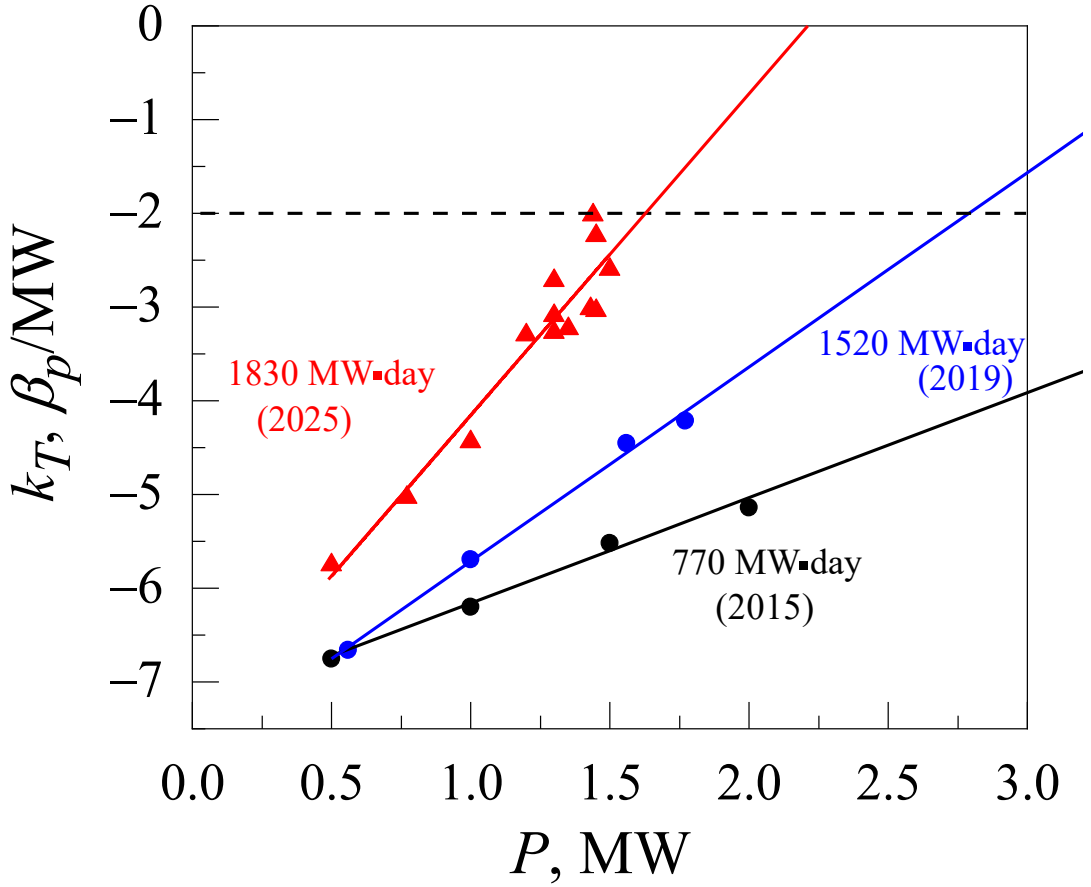
Transient processes caused by square oscillation reactivity Δr_0 (*1*) of the IBR-2M reactor at average power of 0.5 MW (*a*), 1.5 MW (*b*) and 2 MW (*c*). Δe_p – the deviation of the energy power pulse and n – number of power pulses

Impulse response of a power feedback of the IBR-2M



Impulse response of a power feedback of the IBR-2M reactor with energy production of 1800 MW·day (2021) at various average power (0.5, 1.0 and 1.5 MW) and a coolant flow rate of 100 m^3/h

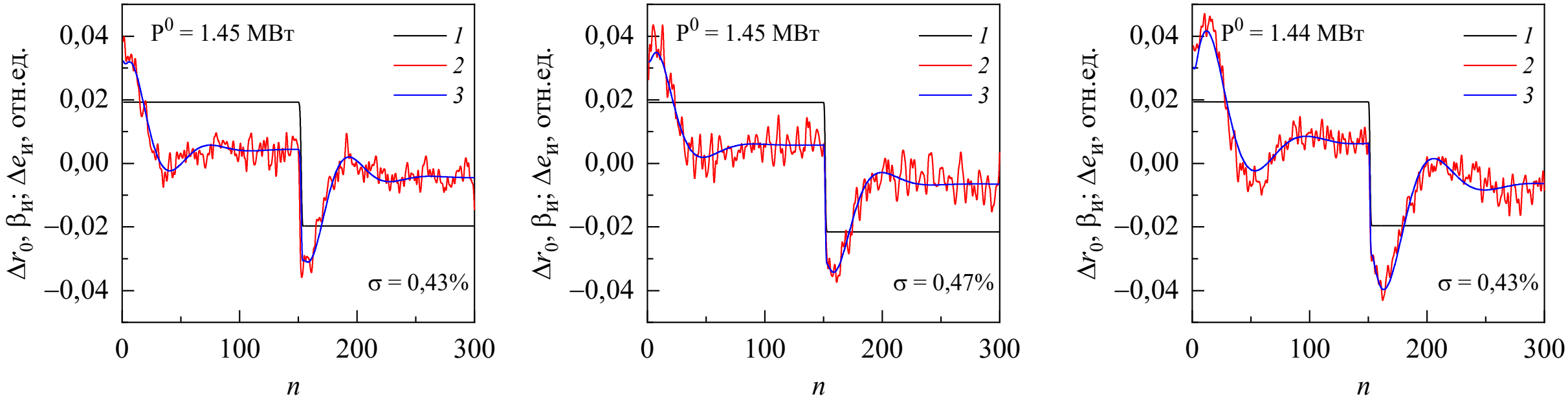
Total transfer coefficient of the power feedback



The transfer coefficient of the PFB $k_T = \sum_{j=1}^{3} k_{Tj}$

dependence on an average power of reactor at various energy output

Approximation of power transient processes

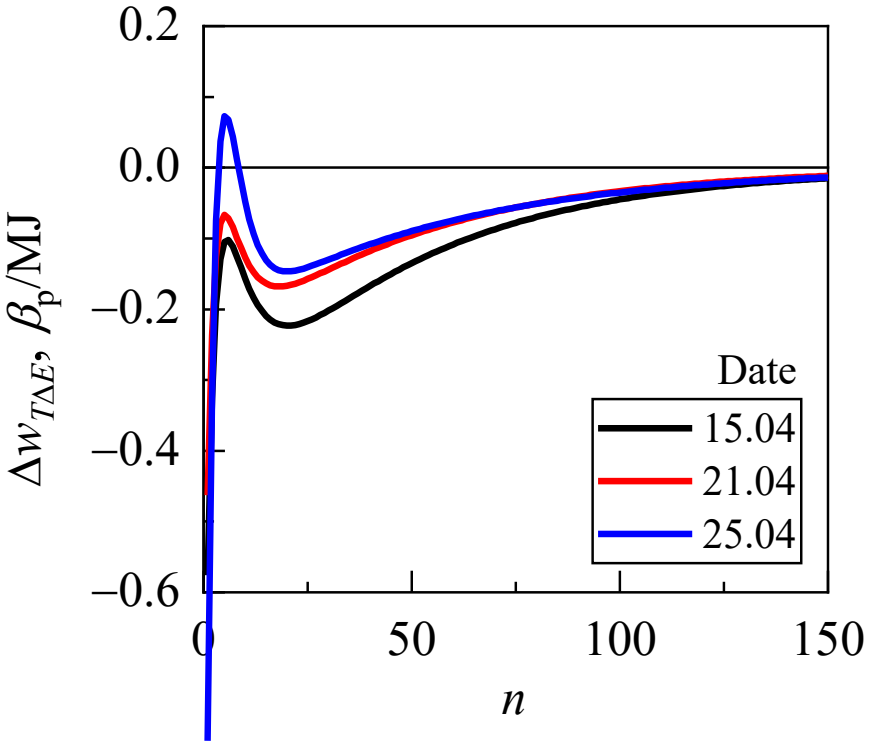


Transient processes caused by rectangular oscillations of the input reactivityΔr_0(*1*), and the oscillation period of the registered $\Delta e_{p.exp}$ (*2*) and calculated $\Delta e_{p.mod}$ (*3*) relative pulse energy deviation at an average power of 1.45 MW. Coolant flow rate: 98 (*a*-*b*) and 96 m³/h (*c*).

Parameters and pulse response of the power feedback

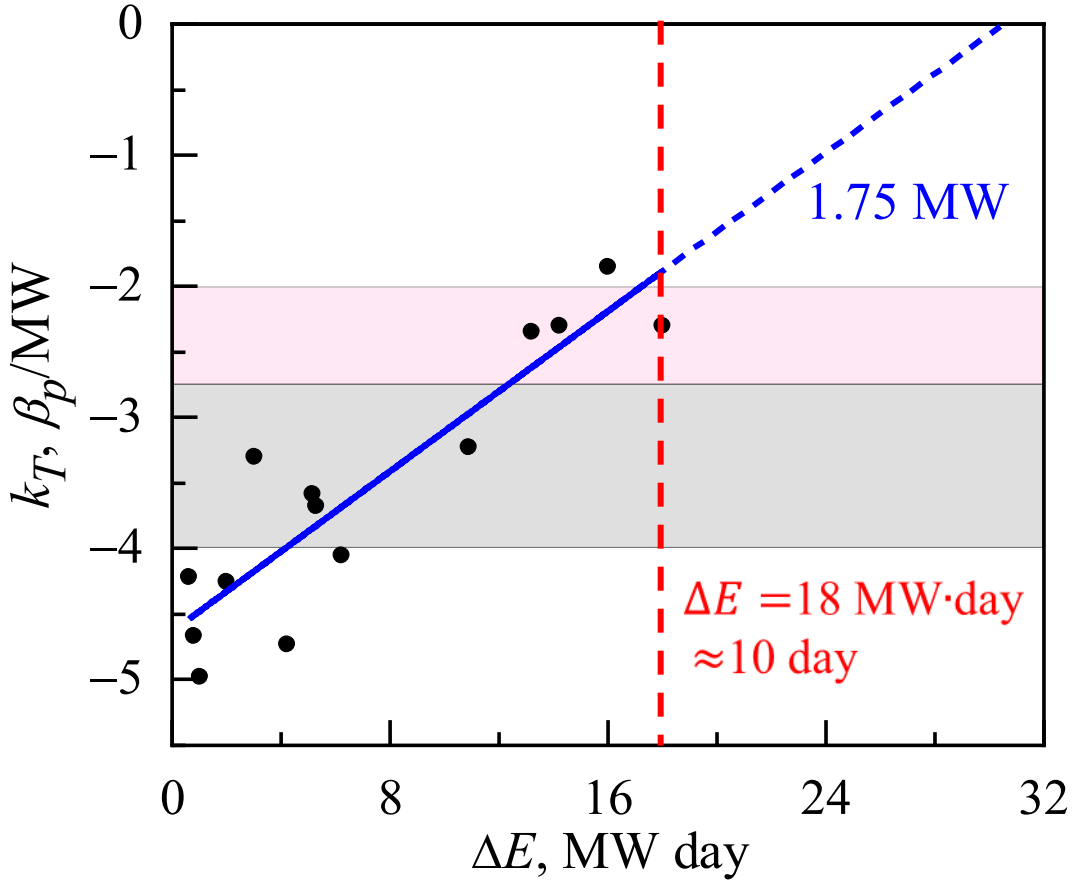
Parameters of the IBR-2M power feedback modeled by three linear aperiodic components

Date	P^0, MW	j	1	2	3	$k_T = \sum k_{Tj}$, β_p/MBT
15.04.2025	1.45	k_{Tj}, β_p/MW	–3.62	0.94	–0.37	–3.05
		T_{Tj}, c	9.06	1.30	0.42	
		c_{Tj}	-	-	-	
21.04.2025	1.45	k_{Tj}, β_p/MW	–2.55	0.64	–0.33	–2.24
		T_{Tj}, c	9.47	0.98	0.39	
		c_{Tj}	-	-	-	
25.04.2025	1.44	k_{Tj}, β_p/MW	–2.39	2.21	–1.84	–2.02
		T_{Tj}, c	10.66	0.68	0.48	
		c_{Tj}	-	-	-	



Pulse response of a power feedback of the IBR-2M pulsed reactor at the start (15.04), middle (21.04), and end (25.04) of cycle No. 3, 2025

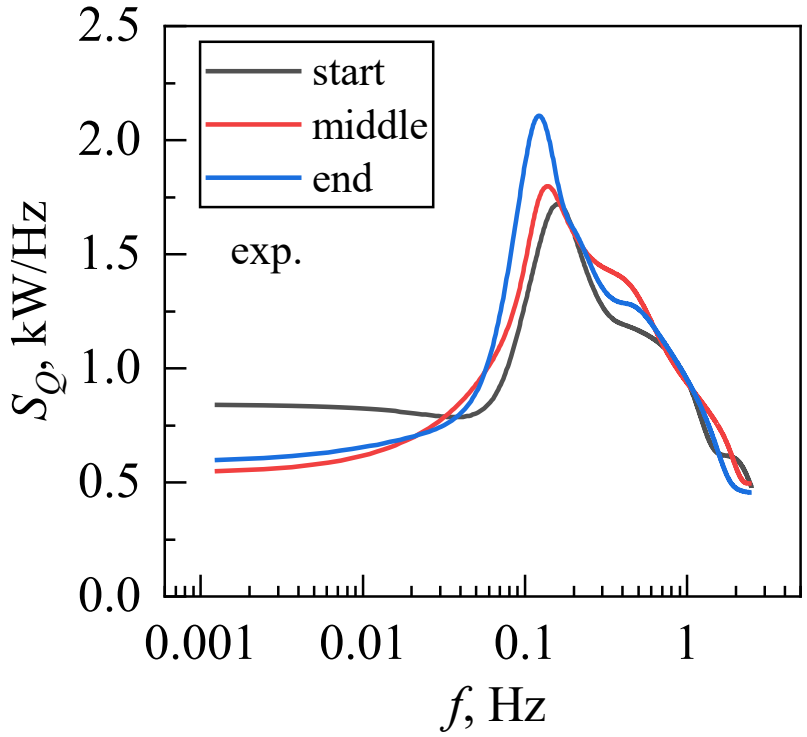
Total transfer coefficient of the power feedback during a reactor cycle



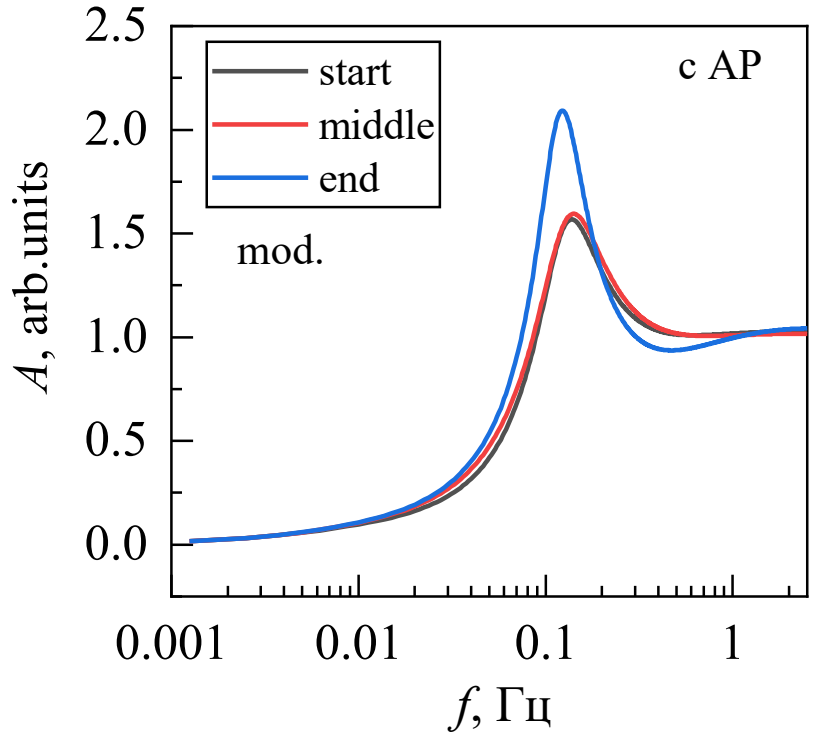
The transfer coefficient of the PFB $k_T = \sum_{j=1}^{3} k_{Tj}$

at an average power of 1.75 MW dependence on energy output during the cycle

Baseline spectra and AFCh of the IBR-2M

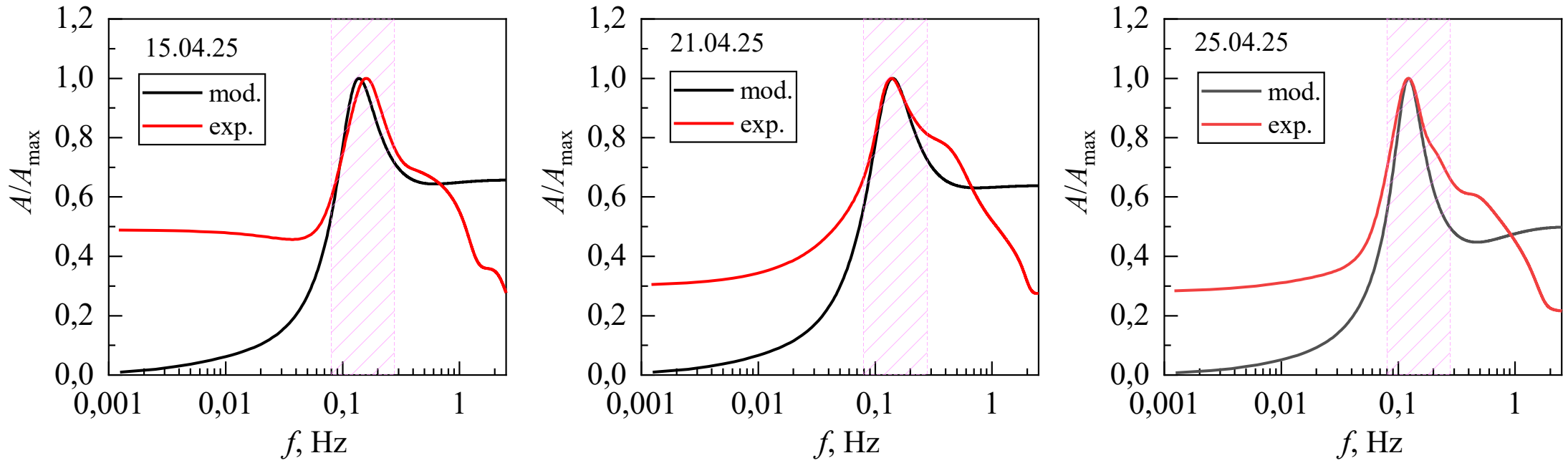


Baseline spectra at the start (April 15), middle (April 21), and end (April 25) of cycle No. 3, 2025.



Amplitude-frequency characteristics of the IBR-2M pulsed reactor at the start, middle, and end of cycle No. 3, 2025."

Baseline spectra and AFCh of the IBR-2M



Baseline spectra and amplitude-frequency characteristics of the IBR-2M
at the start (April 15), middle (April 21), and end (April 25) of cycle No. 3, 2025.

Conclusions

✓The resonant noise component (peak at ~0.1 Hz) matches the reactor's amplitude-frequency characteristic from the dynamics model.

✓This confirms the accuracy of the dynamics model.

✓The basis elements method is applicable for reactor condition monitoring.


Thank you for your attention!