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Generation of high precise data for the verification of computational tools for reactor signal analysis

S. Hübner, C. Lange, W. Lippmann, A. Hurtado
Chair of Hydrogen and Nuclear Energy, Technische Universität Dresden, Germany

V. Lamirand, A. Rais
Laboratory of Reactor Physics and System Behaviour, École Polytechnique Fédérale de Lausanne, Switzerland

C. Pohl, J. Pohlus
Business Unit Nuclear Energy, TÜV Rheinland, Germany

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 754316.
The AKR-2

Training Reactor of the TU Dresden

Homogenous, zero-power reactor with a maximum power of $2 \, W_{\text{thermal}}$
Outline

- Embedding in the European project CORTEX
- Experimental setup
  - Design of the perturbation systems
  - Detector positions
- Comparison of signals
- Applications beyond CORTEX
- Future sight
Embedding in the European project CORTEX

- 11 Countries
- 20 Contributers

Countries

Contributers

[2]
Embedding in the European project CORTEX

Overall goals of the project

Development of innovative methods for reactor core monitoring

- Based on noise analysis of the neutron-flux fluctuations

\[ X(r, t) = X_0(r, t) + \delta X(r, t) \]

- Neutron-flux fluctuations due to statistical character of fission, mechanical vibrations, coolant turbulence, ...

- Develop tools which allow in-situ and in-time core diagnostics
  - Use inverse reactor transfer function

- Show location and type of disturbance source

Power in mW

Time in s

Zero-power reactor answer to oscillating pertubation

Detector positions radial-azimutal [3]
Embedding in the European project CORTEX

Structure

Real power plant data

Simulation tools

Machine learning

Simulated data

Analysis tools

validate

[4]
Embedding in the European project CORTEX

Structure

- Absorber of variable strength
  - Rotating absorber
  - Vibrating absorber

- Vibrating fuel rods
  - COLIBRI [1]

Industrial scale measurement system

compare with
Zero-power transfer function of the AKR-2

Theoretical shape of the zero-power transfer function of the AKR-2, kinetic parameters are calculated with Monte-Carlo codes (MCNP & SERPENT)
Experimental setup at AKR-2
Design of the pertubation systems

Mesh of cross sections of AKR-2 at height of 122, 130 and 138 cm from ground level

Vibrating absorber

Shape and movement of the linear moving absorber
Experimental setup at AKR-2
Design of the perturbation systems

Vibrating absorber

Rotating absorber

Shape and position of the rotating absorber

Shape and movement of the linear moving absorber

Localization of perturbations

Mesh of cross sections of AKR-2 at height of 122, 130, and 138 cm from ground level
Experimental setup at AKR-2
Design of the perturbation systems
Vibrating absorber

Linear support | Aluminium shaft | Fuel
---|---|---
Linear motor axis | Reactor boundary | Absorbing probe

Bearings

Pile-oscillator:
left: Principle of experiment at AKR-2
above: 3D-model
Experimental setup at AKR-2
Design of the perturbation systems
Vibrating absorber

Pile-oscillator:
left: Principle of experiment at AKR-2
above: 3D-model
Experimental setup at AKR-2
Design of the perturbation systems
Rotating absorber

Rotating absorber:
left: cross section figure of principle build
above: 3D-model

Spacer
Shaft
Ball bearings
Absorbing sheet
Experimental setup at AKR-2
Design of the perturbation systems
Rotating absorber

Rotating absorber: left: cross section figure of principle build above: 3D-model
**Experimental setup at AKR-2**

**Design of the perturbation systems**

**Reactivity impact**

Rotating absorber

Total reactivity:  $\rho_t' = 0.0109$ 

<table>
<thead>
<tr>
<th>Angle in °</th>
<th>Differential reactivity in $$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>36</td>
<td>-0.004</td>
</tr>
<tr>
<td>72</td>
<td>-0.008</td>
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<tr>
<td>108</td>
<td>-0.01</td>
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<tr>
<td>144</td>
<td>-0.008</td>
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<tr>
<td>180</td>
<td>-0.006</td>
</tr>
<tr>
<td>216</td>
<td>-0.004</td>
</tr>
<tr>
<td>252</td>
<td>-0.002</td>
</tr>
<tr>
<td>288</td>
<td>0</td>
</tr>
<tr>
<td>324</td>
<td>0.002</td>
</tr>
<tr>
<td>360</td>
<td>0.004</td>
</tr>
</tbody>
</table>

Vibrating absorber

<table>
<thead>
<tr>
<th>Absorberposition from core center in cm</th>
<th>Differential reactivity in $$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.14</td>
</tr>
<tr>
<td>5</td>
<td>0.12</td>
</tr>
<tr>
<td>10</td>
<td>0.1</td>
</tr>
<tr>
<td>15</td>
<td>0.08</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>

Differential reactivity of rotating (left) and linear moving (right) absorber with delayed neutron fraction $\beta = 0.00766$
Experimental setup at AKR-2
Detector positions

- Experimental setup for the generation of high precise data for the verification of computational tools for reactor signal analysis.
- TU Dresden, Chair of Hydrogen and Nuclear Energy / Sebastian Hübner et al.
- Zittau, KompOst doctoral seminars 2018 // 13th December 2018

Detector positions:
1. He-3 proportional counter
2. Fission chamber
3. Fission chamber, wide range
4. γ- compensated ion chamber

Mesh of cross sections of AKR-2 at height of 122, 130 and 138 cm from ground level

Localization of perturbations
Detectors
Comparison of signals

Power spectral density (periodogram) comparison for Rotating Absorber [5]
Applications beyond CORTEX
Vibrating absorber → Pile-oscillator

Pile-oscillator measurement of standard and probe with polynomial fit [6]

\[ \sigma_{a,In} = 202,7 \text{ b} \]
theoretical: 197 b
Deviation of 2.9%
Future sight

After shutdown of BER-II (Berlin), AKR-2 one of two remaining, accessible neutron source sites in Germany

Proved applicability in research.

- Two more measurement campaigns in CORTEX
  - Development of the perturbation and data acquisition systems
- Neutron imaging
- Diffractometer
- Moderator test station
Generation of high precise data for the verification of computational tools for reactor signal analysis

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Sources


[4] V. Lamirand, S. Hübner, First experimental campaigns in AKR-2 & CROCUS reactors, presentation, Annual CORTEX meeting, Munich 2018

[5] V. Lamirand, A. Rais, Qualification of the acquisition systems for experimental campaigns, presentation, Annual CORTEX meeting, Munich 2018


AKR-2 Components

- Fuel
- Reflector
- Control- and Safetyrods
- Experimental Channels
- Shielding
Diffusion equation

Initial condition: critical reactor \((\rho = 0, k = 1)\) \(\rho \ldots \text{reactivity} \quad k \ldots \text{multiplication factor}\)

2-group diffusion equation:

\[
\begin{align*}
\text{Diffusion} & \quad \text{Loss} & \quad \text{Source} \\
\text{Fast neutrons (1)}: & \quad \nabla \cdot (D_1 \nabla \Phi_1) - (\Sigma_{a,1} + \Sigma_m)\Phi_1 + \epsilon v \Sigma_{f,2} \Phi_2 & = n_0 = 0 \\
\text{Thermal neutrons (2)}: & \quad \nabla \cdot (D_2 \nabla \Phi_2) - \Sigma_{a,2} \Phi_2 & = p \Sigma_m \Phi_1 \\
\end{align*}
\]

\(D \ldots \text{diffusion coefficient} \quad \Phi \ldots \text{neutron flux} \quad \Sigma \ldots \text{macroscopic cross section}\)

\(\epsilon \ldots \text{fast fission factor} \quad v \ldots \text{mean velocity} \quad p \ldots \text{resonance escape probability}\)

\[
\rho_a = \frac{-\delta \Sigma_{a,2} \Phi_2 \Phi_2^+ \Delta V}{\int_{V_R} (\Phi_1 + \epsilon v \Sigma_{f,2} \Phi_2 \Phi_1^+) dV}
\]
Zero-power transfer function

\[ H(s) = \frac{\mathcal{L}\{n(t)\}}{\mathcal{L}\{\rho(t)\}} = \frac{N(s)}{R(s)} \]

\[ H(s) = \frac{n_0}{\Lambda \cdot s + \beta - \rho_0 - \sum_{i=1}^{6} \frac{\beta_i \cdot \lambda_i}{s + \lambda_i}} \]

\[ s = i\omega \]

\( \Lambda \) ... mean, eff. generation time of prompt neutrons

\( \beta \) ... fraction of delayed neutrons

\( \lambda \) ... precursor decay constants

\( i \) ... \( i \)th group of delayed neutrons

Zero-power transfer function of the AKR-2 for a sinusoidal input signal
Pile-oscillator evaluation method$^1$

$$\Delta S(m) = \Delta S_0 + A_1 m + A_2 m^2$$

$$A_1 = C \cdot \frac{\Sigma_a}{\rho(m,V)}$$

$$\sigma_{a,u} = \frac{A_{1,u}}{A_{1,s}} \cdot \sigma_{a,s} \cdot \frac{N_{U}(M,\rho)}{N_{S}(M,\rho)}$$

$$\sigma_{a,ln} = 202.7 \text{ b} \quad \text{Theoretical value: 197 b}$$

Deviation of 2.9 %

Deviation of the regressions:

- Iridium (standard) : 2.2 %
- Indium (probe) : 13.7 %
- Sum : 13.9 %

Precision of "old" and "new" Pile-oscillator

Mean deviation:
- 2.44 %
- 0.22 %

Normalized counts

Indium Proben Hübner
Indium Proben Klass
Simulated neutron flux in experimental channels of AKR-2

Simulated, normalized neutron-flux in:

Tangential channel 3-4

Central channel 1-2

Reactivity in $\text{°}$

Angle in $\text{°}$
Reactor signals of AKR-2, examples

Messspannung in V

Zelt in s

150 160 170 180 190 200
Reactor signals of AKR-2, examples
Data Acquisition System, ISTEC

V. Lamirand, A. Rais, *Qualification of the acquisition systems for experimental campaigns*, presentation, Annual CORTEX meeting, Munich 2018
V. Lamirand, A. Rais, *Qualification of the acquisition systems for experimental campaigns*, presentation, Annual CORTEX meeting, Munich 2018
Data Acquisition System, TUD

Detector Signal
Input
Pulse mode
detector signal

Data Acquisition Unit
Multi-Channel-Scaler
EASY-MCS (ORTEC®)

Specifications:
- 65536 channel
- Max. of 1,073,741,823 (30 Bit) counts per channel
- Max. sampling rate 150 MHz
- Dwell time from 100 ns to 1300 s with max. failure ± 100 ppm
- Min. pulse height 30 mV
- No dead time between channels
- Save the acquired data

Control Unit
Laptop with software to read the saved data and control the data acquisition system (via USB 2.0):
- number of channels
- dwell time
- discriminator level (between -1.6 V and 3 V)

V. Lamirand, A. Rais, Qualification of the acquisition systems for experimental campaigns, presentation, Annual CORTEX meeting, Munich 2018