PISTIL, A reactivity modulation device to probe the transfer function of the research nuclear reactor CROCUS

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ABSTRACT

The PISTIL device targets the determination of **precursor abundances** by reactivity modulation. We here present its design and testing in the CROCUS reactor at EPFL. It is capable of generating periodic modulations between 1 mHz and 200 Hz. The modulation can either be continuous or following stepwise a predefined motion profile. Thanks to the mechanical design, its reactivity worth and modulation amplitude are tuneable.

MOTIVATIONS

IMPROVED REACTOR KINETIC PARAMETERS

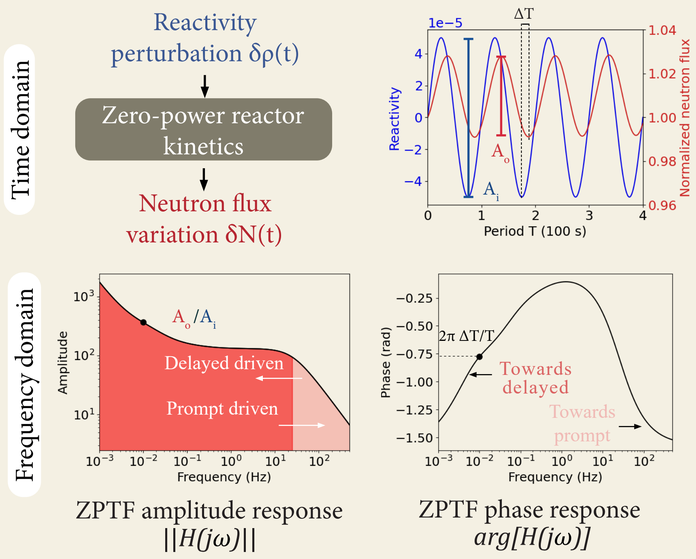
- Uncertainty and bias reduction in delayed neutron parameters for better reactivity estimate in reactor operation and safety studies
- Towords improved knowlege of delayed neutron data and validation of calculation models

ZERO-POWER TRANSFER FUNCTION (ZPTF)

- Reactor response to reactivity perturbations
- Frequency-dependent sensitivity to delayed and prompt neutrons

EXPERIMENTAL APPROACH

- Development of a reactivity modulation device to generate controlled modulation covering frequency ranges of interest (~1 mHz to ~100 Hz)
- Mechanical qualification and reactivity calibration
- Fourier analysis of neutron flux variations resulting from modulation

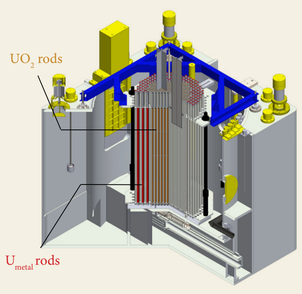


ZPTF amplitude response $||H(j\omega)||$

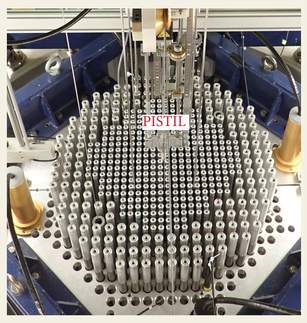
ZPTF phase response $arg[H(j\omega)]$

$$H(j\omega) = \frac{1}{j\Lambda\omega + \sum_i^n \frac{j\beta_i\omega}{j\omega + \lambda_i}}$$

ω	Angular frequency (rad.s^{-1})
Λ	Prompt neutron generation time (s)
β_i	Delayed neutron fractions of the i-th group
λ_i	Precursor decay constantant of the i-th group (s^{-1})



Cross-sectional view of CROCUS



PISTIL installed in the core center of CROCUS

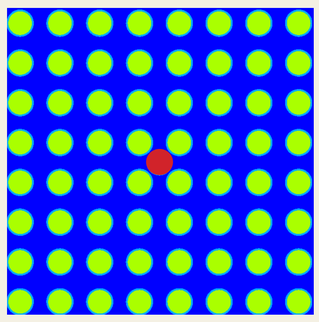
CROCUS REACTOR

- Pool type light water reactor
- Maximum power of 100 W
- Reactivity control by B_4C rods or spillway (in-core water level variation)
- Interlocked fuel zones of 1.806 wt.% UO_2 lattice and 0.947 wt.% U_{metal} lattice
- Active core of 60 cm in diameter and 1 m in height
- PISTIL inserted in the core center

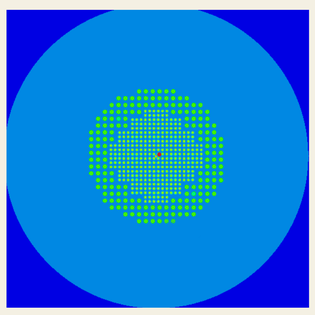
PERIODIC REACTIVITY INJECTION SYSTEM TRANSIENT INDUCED LOCALLY (PISTIL)

DESIGN METHODOLOGY

Numerical simulation of reactivity modulation experiment
→ Dimensionning
→ Neutronic design
↔ TRIPOLI4 Monte Carlo simulation / Feasibility; Impact of structure material
→ Mechanical design



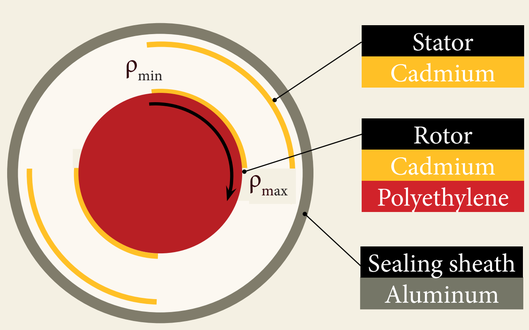
Modulator in a 8x8 UO_2 lattice: Proof of concept and material selection



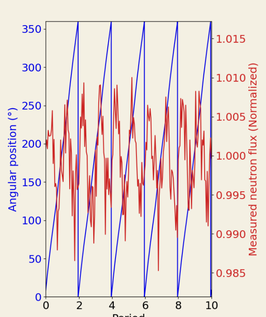
Modulator in CROCUS: Estimation of reactivity worth and modulation effect

CHARACTERISTICS

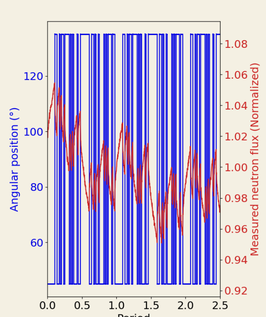
- System of rotary (rotor) and stationnary (stator) components
- Reactivity modulation through recovery and discovery in angular position of rotor and stator cadmium elements
- 2-fold rotational symmetry (180°) for frequency doubling in modulation
- Configurable axial positioning
  - 600 mm range for the rotor-stator ensemble as reactivity tuning
  - 100 mm range for stator as modulation amplitude modification
- Constant frequency rotation or repetition of predefined motion profile
- Asymptotic period calibration of the maximum modulation amplitude (rotor-stator at 550 mm water level)
  - 0.492 ± 0.002 ¢ (ENDF-B.VII.0)
  - 0.570 ± 0.002 ¢ (JEFF-3.1.1)



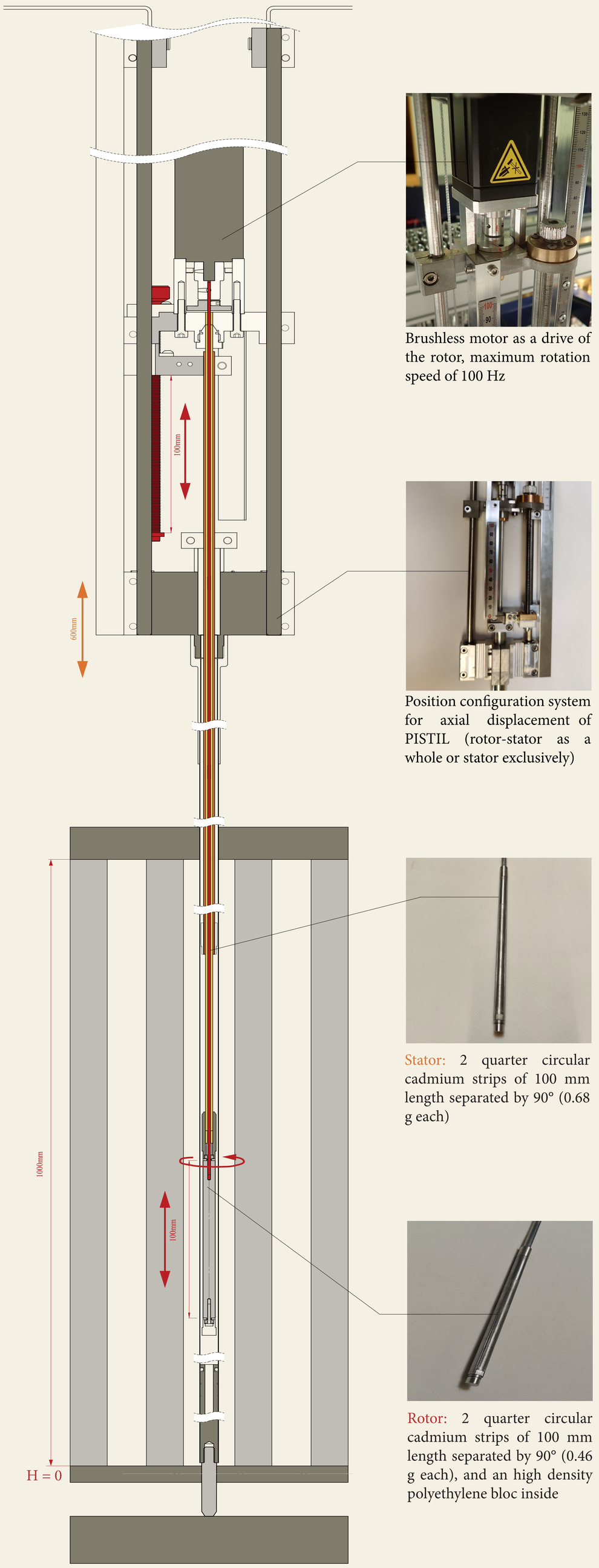
Main active components of PISTIL



Measured flux profile during constant frequency rotation



Measured flux profile during a pseudo random sequence movement



Brushless motor as a drive of the rotor, maximum rotation speed of 100 Hz

Position configuration system for axial displacement of PISTIL (rotor-stator as a whole or stator exclusively)

Stator: 2 quarter circular cadmium strips of 100 mm length separated by 90° (0.68 g each)

Rotor: 2 quarter circular cadmium strips of 100 mm length separated by 90° (0.46 g each), and an high density polyethylene bloc inside

CONCLUSION AND PERSPECTIVES

- PISTIL: a device allowing controlled and known in-core reactivity modulation for zero-power transfer function measurements
- Contribution to consistent and accurate kinetic parameter evaluation through experimental investigation
- First experimental campaign in CROCUS conducted from May to June 2021, modulation frequency ranging from 1.6 mHz to 200 Hz
- Second experimental campaign planned in Autumn 2021, benefiting from early analysis and using updated neutron detection instrumentation