DE LA RECHERCHE À L'INDUSTRIE

Some «hints» for discussion on the validation of models on the 1st CROCUS experimental campaign

CORTEX
Core monitoring techniques and experimental validation and demonstration

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OUTLINE

- Repeatability of experimental measurements
  - Experiment #2, #3, #20
- Analysis of COLIBRI movement
- A simple Point-Kinetic model
  - The MatLab model
  - Short remark on exp. data treatment
  - Kinetic parameters computed with APOLLO3
- Question and conclusions
- Next steps

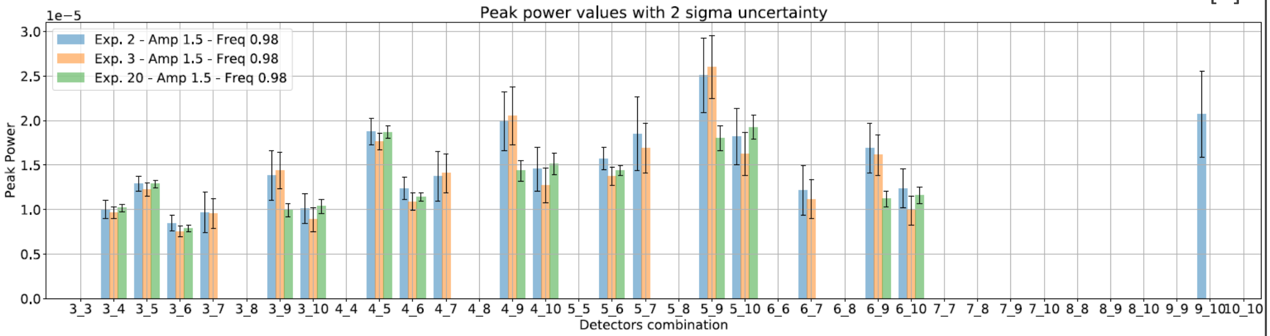
REPEATABILITY OF EXPERIMENTS

- Looking at [1], experiment #2, #3, #20, once the signal is normalized to the same reactor power, should give the same results.

Experiment repeatability

Measurements 2, 3 and 20 are equivalent: Amplitude: 1.5 mm, Frequency 1 Hz

From [2]



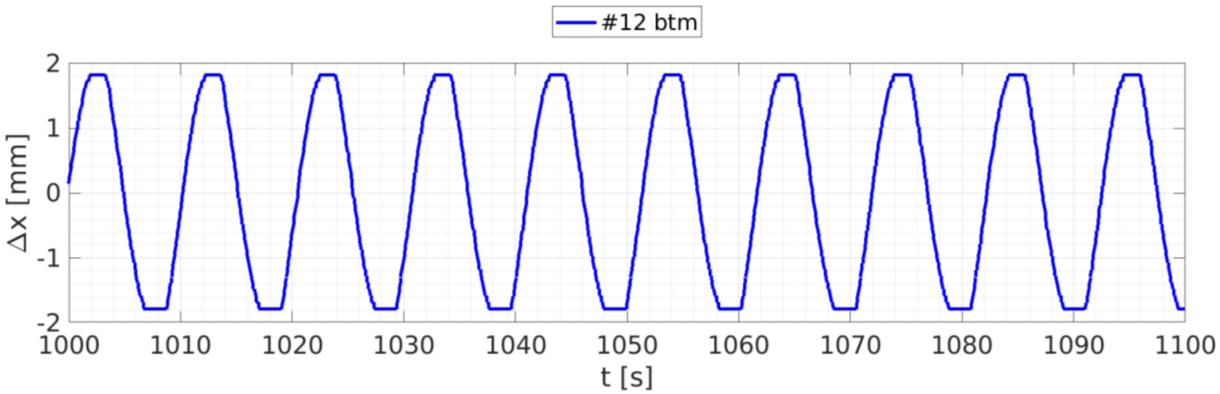
All the CPSDs (x,9) show that the uncertainty intervals do not overlap.

What can we conclude from this? The error bar should be larger or Det#9 is not reliable?

[1] V. Lamirand et al., Experimental report on the 1st campaign at AKR-2 and CROCUS, CROTEX – D2.1.
[2] A. Rais et al., CROCUS campaign experimental results, June 28, 2019.

ANALYSIS OF COLIBRI MOVEMENT (I)

- For a correct simulation of COLIBRI, it is **fundamental** to know the amplitude of oscillation in the most accurate way possible
- So it is worth to take a look at the measured displacement of the CROLIBRI plates (offset the time signal at zero mean value)
- Displacement file → in mm?



ANALYSIS OF COLIBRI MOVEMENT (II)

Considering the amplitude of oscillation of the top and bottom plate of COLIBRI, for some experiments [1]:

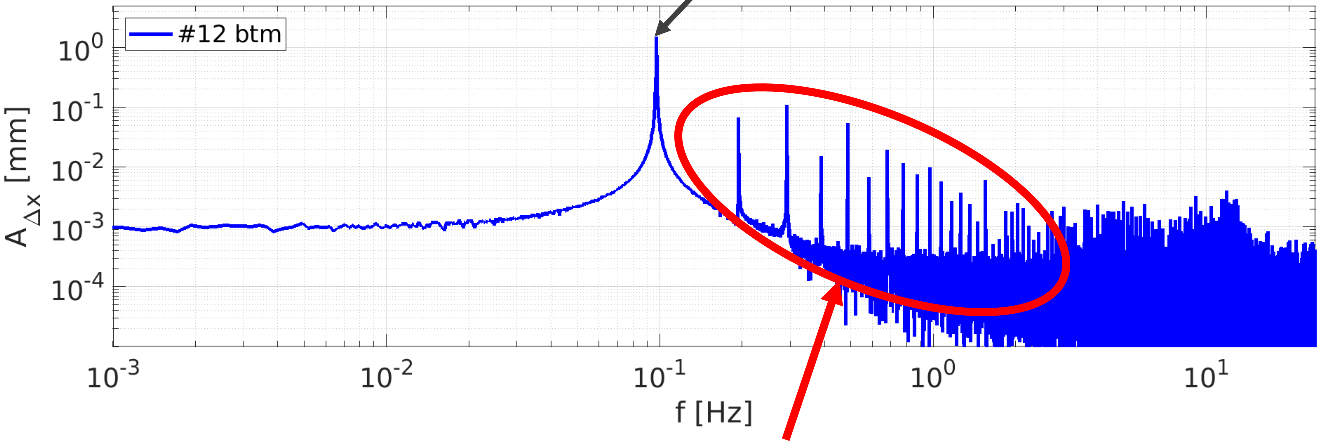
Exp. #	f [Hz]	A_i	A_m
2	1.0	1.5	3.2
3	1.0	1.5	3.2
4	0.5	1.5	3.0
6	2.0	1.5	4.5
8	0.5	0.5	0.7
11	0.5	2.0	3.7
12	0.1	2.0	3.7
18	2.0	1.5	3.3
20	1.0	1.5	3.2

- A_i : requested amplitude of oscillations
- A_m: measured amplitude of oscillation → is this the amplitude to be used in the simulation?

… There's quite a difference between the two. **Which is the exact amplitude to be given as input to the models?** Here there are some considerations…

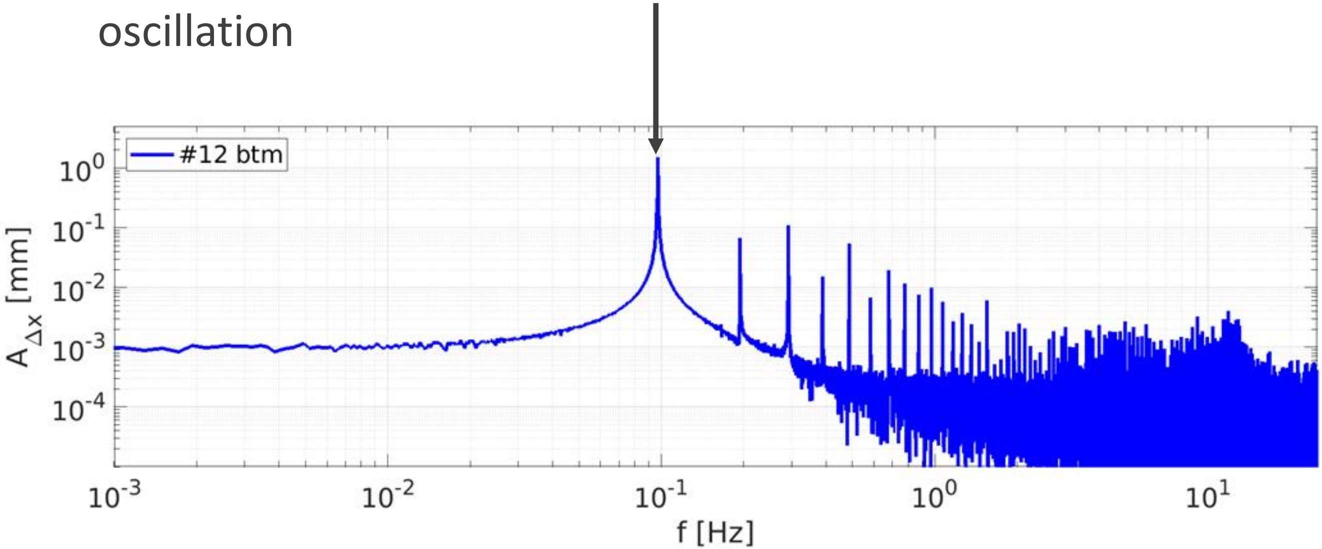
- Fourier transform of the displacement file *(CROCUS_XX_COLIBRI_top[bottom].txt)*
- *Bell-shaped* curve around the frequency of oscillation → for the simulations take the peak

Considered amplitude for bottom plate



Is it possible that these “spikes” at multiple $n\omega_0$ are responsible of the peak at multiple $n\omega_0$ observed in several experiments???

- **Is it more likely that the measured A_m (see slide 5 and 7) is the result of the sum of the contributions from all the harmonics of the movement?**
- The model(s) accounts for a *monocromatic* oscillation → one amplitude as input → the peak amplitude at the frequency of oscillation



Considering the amplitude of oscillation of the top and bottom plate of COLIBRI, for some experiments [1]:

Exp. #	f [Hz]	A_i	A_m	A_{top}	A_{bottom}	Note
2	1.0	1.5	3.2	1	1.29	
3	1.0	1.5	3.2	1	1.29	
4	0.5	1.5	3.0	1.14	1.52	
6	2.0	1.5	4.5	0.9	2.097	High frequencies seem to suffer more from the COLIBRI inertia, see Exp.#18
8	0.5	0.5	0.7	0.287	0.252	
11	0.5	2.0	3.7	1.56	1.91	
12	**0.1**	**2.0**	**3.7**	**n.a.**	**1.496**	**Top displacement not available. So it has been estimated 0.4mm smaller from looking at the values for Exp.#4, #11 (similar ω_0)**
18	2.0	1.5	3.3	0.5	1.2	High frequencies seem to suffer more from the COLIBRI inertia, see Exp.#6
20	1.0	1.5	3.2	1	1.29	

A SIMPLE POINT KINETIC MODEL: THE MATLAB MODEL

A simple Point Kinetic model has been implemented in MatLab. The equations from [3] assume *ND* = 6 and *Q*(*t*) = 0:

$$\begin{cases} \dfrac{dT(t)}{dt} = \dfrac{\rho-\beta}{\Lambda}T(t) + \displaystyle\sum_{i=1}^{ND}\lambda_i C_i(t) + Q(t) \\ \dfrac{dC_i(t)}{dt} = \dfrac{\beta_i}{\Lambda}T(t) - \lambda_i C_i(t) \quad , \qquad i = 1, ND \end{cases}$$

$$\beta = \sum_{i=1}^{ND}\beta_i$$

The kinetic parameters are taken from [1][4], referring to the results of the HEXNOD data (ENDF/B-4 data)

[10^{-3} s]						
β	β_1	β_2	β_3	β_4	β_5	β_6
7.1855	0.2458	1.4461	1.3226	2.9034	1.0267	0.2409

[10^{-5} s]	[s^{-1}]	[s^{-1}]	[s^{-1}]	[s^{-1}]	[s^{-1}]	[s^{-1}]
Λ	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6
5.7000	0.01275	0.03178	0.11911	0.31806	1.4024	3.9238

[3] A. F. Henry, Nuclear-Reactor Analysis, The MIT Press, 1986.
[4] Benchmark on Kinetics Parameters in CROCUS, NEA/NSC/DOC/(2006)1

In the following analysis the experimental data are treated according to CEA strategy, including the suggestion from EPFL.

Briefly:

- All the (raw) signals have been normalized in order to have an **unitary** level of average **power**, in order to be able to compare the detectors among each others

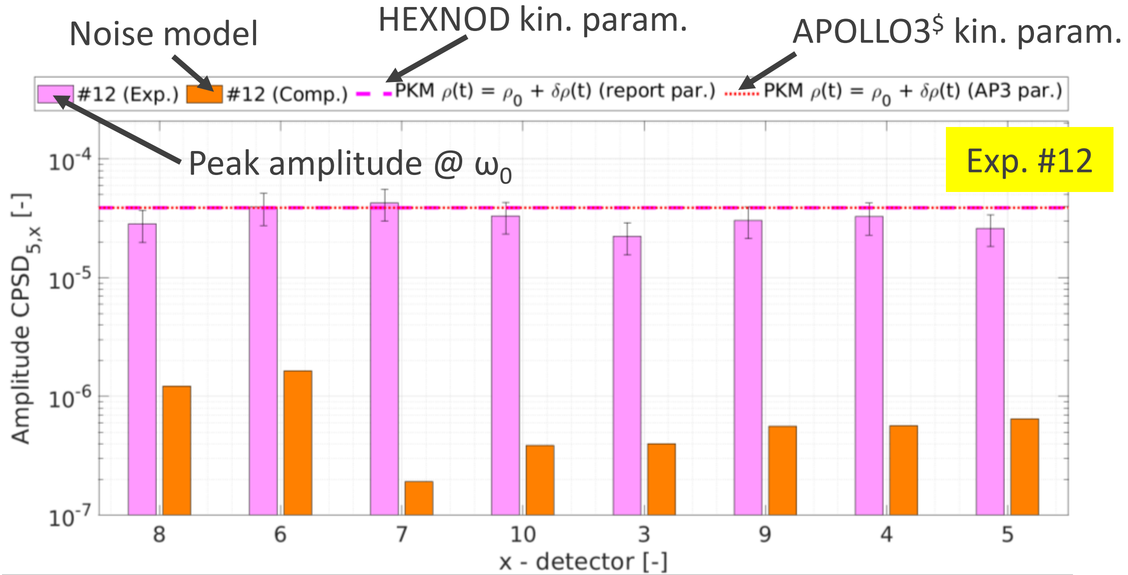
$$\tau^*(t) = \frac{\tau(t)}{A_{\omega=0}}$$

Amplitude of the harmonic at ω=0Hz

- CPSDs have been computed, using Det#5 as reference detector (no ratios computed).

A SIMPLE POINT KINETIC MODEL: THE MATLAB MODEL

- $\rho(t)$ determined from the sequence of the static calculation with 1.25 mm displacement* → the point kinetic approximation is suitable [5]
- The kinetic parameters are those provided by HEXNOD data [1][4].



This exercise allowed to point out that the noise model has some problems

*** Exp. #12 the amplitude of the oscillation for the top plate is *reasonably* assumed to be around 1 mm. So use as *effective* amplitude of oscillation for the central plane an intermediate/average value between the top and bottom plate displacements, see slide 8.**

[5] D. L. Hetrick, Dynamics of Nuclear Reactors, 1971.

A SIMPLE POINT KINETIC MODEL: KINETIC PARAMETERS COMPUTED WITH APOLLO3

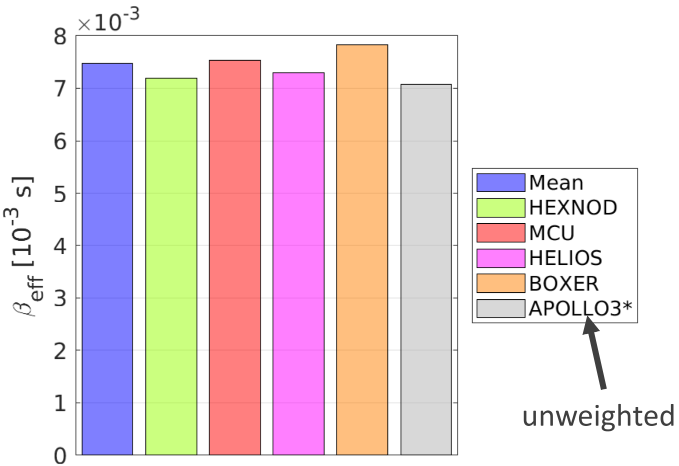
- **Kinetic parameters estimated with APOLLO3 noise model** using ND = 8, and W = 1 and NF fissile isotopes, so from the definition [3]:

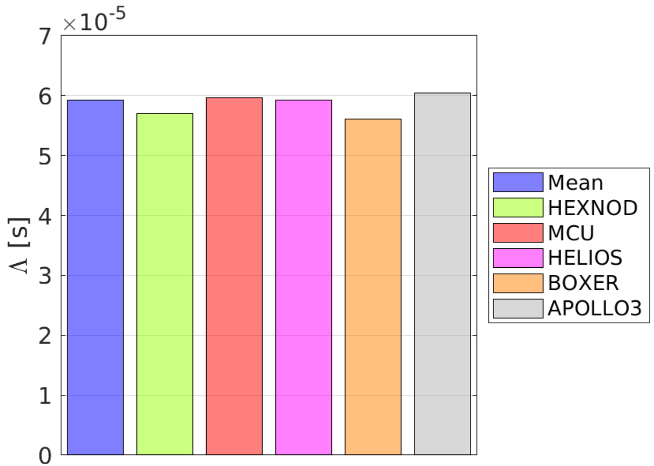
$$F_T = \int dV \int dE\, W \sum_j^{NF} \left\{ \chi_p^j (1-\beta^j) + \sum_i^{ND} \chi_j \beta_i^j \right\} F^j S$$

$$\beta_i = \frac{\int dV \int dE\, W \sum_j^{NF} \chi_j \beta_i^j F^j S}{F_T}$$

$$\beta_{eff} = \sum_i^{ND} \beta_i$$

$$\Lambda = \frac{\int dV \int dE\, W (1/v) S}{F_T}$$





[3] A. F. Henry, Nuclear-Reactor Analysis, The MIT Press, 1986.

- What can we conclude concerning the experimental **repeatability**? Is **Det#9 reliable**?

- Do you agree that the **approach** of the determination of the **effective amplitude of oscillation reasonable**?

- Imposing the **amplitude** of oscillation **form** the Fourier analysis of the actual **COLIBRI** displacement, a **simple** point kinetic model **captures at least the order of magnitude of the signal**

- **APOLLO3 noise** temporal **model** is able to **reproduce** the **β and** ***Λ*** **parameters**

NEXT STEP

- Comparing the results of the experiment, the simple point kinetic model and the APOLLO3 results we have the **strong suspect** that something is missing in the model in the model or at least not properly simulated… we are currently investigating on this.

Merci pour votre attention