Preliminary study of fuel assembly vibrations in a nuclear reactor

A. Vidal-Ferràndiz[♭], D. Ginestar[‡][*], A. Carreño[♭], G. Verdú[♭],

(♭) Instituto de Seguridad Industrial: Radiofísica y Medioambiental,
Universitat Politècnica de València, Camino de Vera, s/n, 46022, València,
(‡) Instituto Universitario de Matemática Multidisciplinar,
Universitat Politècnica de València, Camino de Vera, s/n, 46022, València.

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1 Introduction

Being able to monitor the state of nuclear reactors while they are running at nominal conditions is a safety requirement. The early detection of anomalies gives the possibility to take proper actions before such problems lead to safety concerns or impact plant availability. The CORTEX project [1], funded by the European Commission in the Euratom 2016-2017 work program, aims at developing an innovative core monitoring technique that allows detecting anomalies in nuclear reactors, such as excessive vibrations of core internals, flow blockage, coolant inlet perturbations, etc. The technique is based on primarily using the inherent fluctuations in neutron flux recorded by in-core and ex-core instrumentation, often referred to as neutron noise, from which the anomalies will be detected.

In this work, we aim to simulate the neutron field behaviour of nuclear reactor when one fuel assembly is vibrating. These vibrations cause neutron flux and power oscillations, also known as neutron noise [3]. Similar studies have been performed in the time domain [5] and in the frequency domain [6].

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[*] e-mail:dginesta@mat.upv.es

To study the neutron flux fluctuations due to bundle vibrations it is necessary to simulate them accurately. The simulation is performed with a continuous Galerkin finite element method and a semi-implicit numerical time integration [4]. The small amplitude of the fuel assembly vibrations makes an accurate simulation of the neutron power evolution a challenging problem. One dimensional numerical examples are studied in this work.

2 Results

In order to test the numerical tools developed a simple one dimensional benchmark is defined. The benchmark is composed of 11 assemblies of 25 cm where the vibrating assembly is placed in the middle of the reactor as Figure 1 shows. The cross sections are defined in Table 1 and zero flux boundary conditions are imposed. The problem is made critical before starting the time dependent calculation.

The oscillation of the central assembly is defined as

$$x_i(t) = x_{i0} + A\sin(2\pi f t), \tag{1}$$

where $x_i(t)$ is each position of the vibrating assembly along time, originally placed in x_{i0}. A is the oscillation amplitude and f is the oscillation frequency.

Figure 2 shows the total power evolution for an oscillation of 1 mm of amplitude and a frequency of 1 Hz along 10 periods. It can be seen a sinusoidal change in the total power with a really small amplitude, about 7.87e-8, with a constant increment along time. This increment is caused because the reactor is supercritical when the central assembly moves from its starting position. Figure 3 displays the static k_{eff} through the positions travelled during one period. It can be seen that the change in the k_{eff} is less that 1.2e-9. The behaviour of the total power was solved analytically in a point kinetic reactor in [2].

In these Figures, 2 non-equidistant meshes are compared. One mesh with 47 cells and a second mesh with the double of cells, 94. Also a uniform mesh with 17600 cell is compared. All computations are calculated with 5th degree polynomials in the finite element method. These meshes display almost equal results. Then, the results with the local 47 cells mesh are converged.

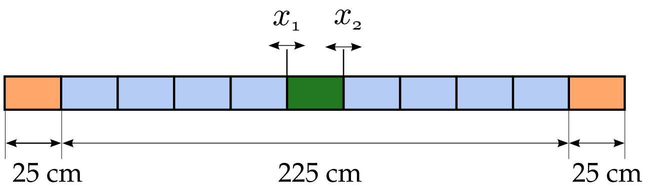


Figure 1: Geometry of the one dimensional benchmark.

Table 1: Cross sections of the materials of the one dimensional benchmark.

Material	**g**	$\mathbf{D_g}$ (cm)	$\boldsymbol{\Sigma_{ag}}$ (1/cm)	$\boldsymbol{\nu\Sigma_{fg}}$ (1/cm)	$\boldsymbol{\Sigma_{fg}}$ (1/cm)	$\boldsymbol{\Sigma_{12}}$ (1/cm)
Fuel	1	1.40343	1.17659e–2	5.62285e–3	2.20503e–3	1.60795e–2
	2	0.32886	1.07186e–1	1.45865e–1	5.90546e–2	
Vibrating	1	1.40343	1.17659e–2	5.60285e–3	2.19720e–3	1.60795e–2
Assembly	2	0.32886	1.07186e–1	1.45403e–1	5.88676e–2	
Reflector	1	0.93344	2.81676e–3	0.00000e+0	0.00000e+0	1.08805e–2
	2	0.95793	8.87200e–2	0.00000e+0	0.00000e+0	

Figure 4 shows the neutron power evolution for different oscillation amplitudes from 0.3 mm to 3 mm while the frequency is fixed to 1 Hz. Obviously as the oscillation amplitude increases its effect in the total power increases. Figure 5 displays the spatial resolution of the neutron flux in 4 different time stamps.

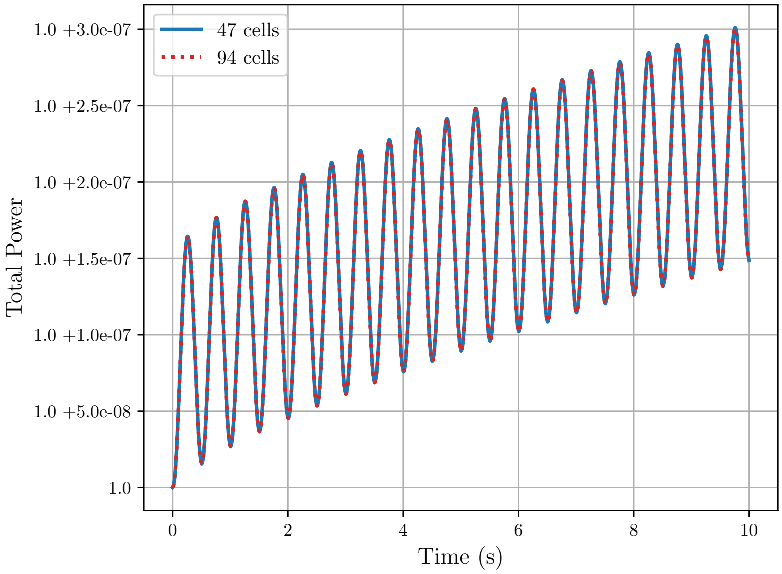


Figure 2: Total neutron power along 10 periods.

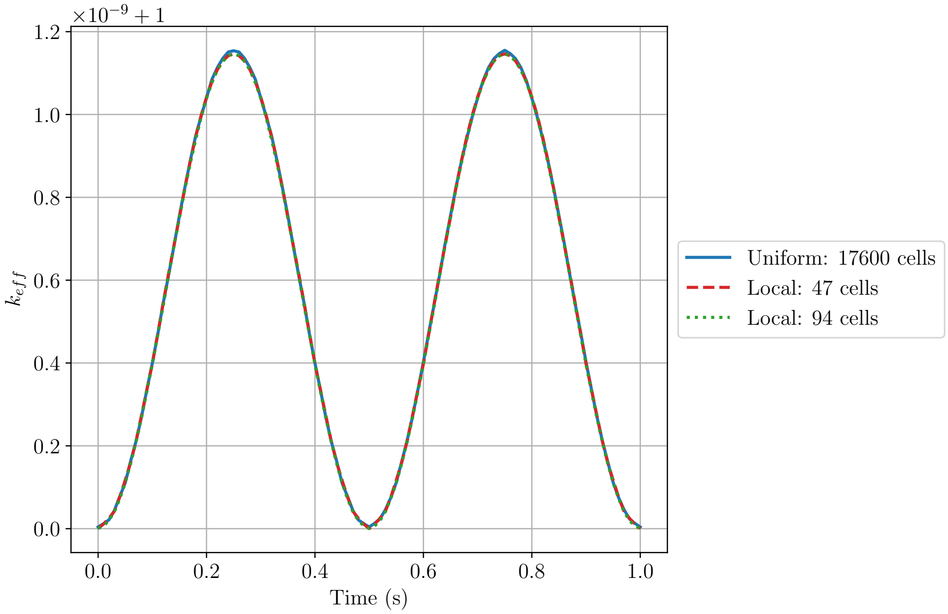


Figure 3: Multiplicative factor along one period.

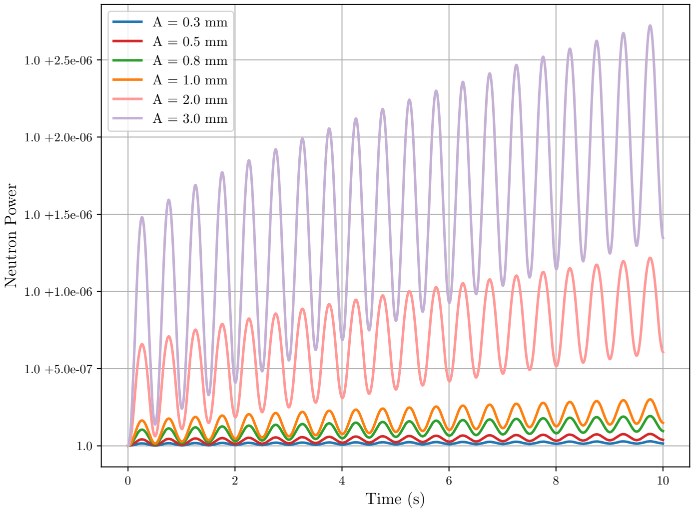
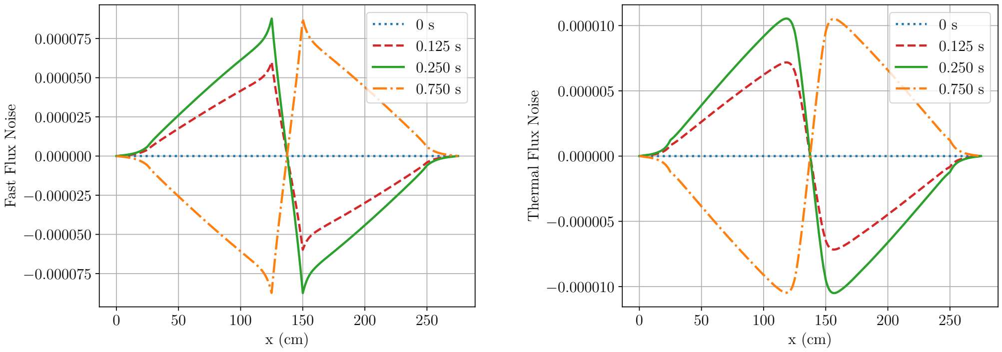


Figure 4: Total neutron power evolution for different oscillation amplitudes.



(a) Fast neutron flux noise

(b) Thermal neutron flux noise

Figure 5: Evolution of the neutron noise.

3 Conclusions

A time-domain FEM kinetic code is being developed to solve the neutron distribution inside a nuclear reactor with vibrating assemblies. The results show that the variation in the k_{eff} is about 10^{-8} in the transient and the variation in the total power is around 10^{-9} for an oscillation with an amplitude of 1 mm. This implies that we need to work with a very high precision. These initial results show that fuel assembly vibration cannot cause large noise instabilities in normal conditions without a coupling with thermal-hydraulics system or several fuel assembly vibrations.

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