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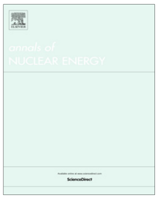

Inverse kinetics for subcritical systems with external neutron source

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ABSTRACT

Nuclear reactor reactivity is one of the most important properties since it is directly related to the reactor control during the power operation. This reactivity is influenced by the neutron behavior in the reactor core. The time-dependent neutrons behavior in response to any change in material composition is important for the reactor operation safety. Transient changes may occur during the reactor startup or shutdown and due to accidental disturbances of the reactor operation. Therefore, it is very important to predict the time-dependent neutron behavior population induced by changes in neutron multiplication.

Reactivity determination in subcritical systems driven by an external neutron source can be obtained through the solution of the inverse kinetics equation for subcritical nuclear reactors. The main purpose of this paper is to find the solution of the inverse kinetics equation the main purpose of this paper is to device the inverse kinetics equations for subcritical systems based in a previous paper published by the authors (Gonçalves et al., 2015) and by (Gandini and Salvatores, 2002; Dulla et al., 2006). The solutions of those equations were also obtained. Formulations presented in this paper were tested for seven different values of k_{eff} with external neutrons source constant in time and for a powers ratio varying exponentially over time.

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1. Introduction

Nuclear reactor transient situations can be predicted only by the neutron flux modification and as a result, it is possible to make a sufficiently accurate prediction about the consequences of the transients. It is sufficient to relate the magnitude of the time-dependent neutron flux with the neutron population in the nuclear reactor core. The point kinetics equations relate these functions and thus allow the study of the transients that may occur in a nuclear reactor, and its obtaining occurs from an approximations sequence from the neutron transport theory. The point kinetics equations may be performed directly from the neutron transport equation to the neutron diffusion equation, or by means of a heuristic procedure according to Duderstadt and Hamilton (1976) and Bell and Glasstone (1970).

Reactivity can be predicted through the reactor inverse kinetic model. This model results from the space dependence separation, assuming a time-independent flux, separated from a time-dependent amplitude function (Lamarsh and Baratta, 2001).

In practice, the use of point kinetics equations takes place in the so-called inverse kinetics where the reactivity is obtained from the nuclear power history (Duderstadt and Hamilton, 1976). There are only a few problems that it is possible to obtain an accurate analytical solution for the neutrons density given a specific reactivity. Indeed, it is often more appropriate to inverse the reactivity calculation problem to determine past neutron density behavior expressed from a direct nuclear power relationship. This procedure is more closely related to the nuclear reactor control methodology according to Bell and Glasstone (1970).

When the neutron production rate via fission reactions is exactly balanced with neutrons leakage and absorption loss, the reactor operates at a constant power level. Any deviation from this balance condition will result in a time-dependent neutron population, consequently, the reactor power will also be time-dependent (Bell and Glasstone, 1970; Duderstadt and Hamilton, 1976; Caro, 1976).

The formalism for reactivity will be developed from the set of point kinetic equations obtained by Gonçalves et al. (2015) in Section 2. The Sections 3 and 4 will present the reactivity obtained from the sets of point kinetic equations proposed by Gandini and Salvatores (2002), and Dulla et al. (2006). In order to analyze the inverse kinetic formulation developed in the Sections 2,3 and 4, the tests results as well as the analysis for seven different

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Table 1
Kinetic parameters by Gonçalves et al. (2015).

Kinetic parameters	0.930	0.940	0.950	0.960	0.970	0.980	0.990
Λ_G	1.64812E−03	1.62131E−03	1.59587E−03	1.57239E−03	1.55020E−03	1.52969E−03	1.51078E−03
Γ_G	−7.52316E−02	−6.38221E−02	−5.25452E−02	−4.16567E−02	−3.08541E−02	−2.03282E−02	−1.00475E−02
q_G	7.52316E−02	6.38221E−02	5.25452E−02	4.16567E−02	3.08541E−02	2.03282E −02	1.00475E−02
β_1^G	2.50047E−04	2.49830E−04	2.49692E−04	2.49631E−04	2.49643E−04	2.49725E−04	2.49872E−04
β_2^G	1.40101E−03	1.39985E−03	1.39911E−03	1.39878E−03	1.39884E−03	1.39927E−003	1.40005E−03
β_3^G	1.23789E−03	1.23676E−03	1.23604E−03	1.23572E−03	1.23578E−03	1.23620E−003	1.23697E−03
β_4^G	2.67391E−03	2.67191E−03	2.67064E−03	2.67009E−03	2.67019E−03	2.67094E−003	2.67228E−03
β_5^G	8.41506E−04	8.40834E−04	8.40406E−04	8.40219E−04	8.40256E−04	8.40507E−004	8.40963E−04
β_6^G	1.70891E−04	1.70758E−04	1.70673E−04	1.70636E−04	1.70643E−04	1.70693E−004	1.70784E−04
β^G	6.57526E−03	6.56994E−03	6.56656E−03	6.56507E−03	6.56535E−03	6.56733E−003	6.57091E−03

Table 2
Kinetic parameters by Gandini and Salvatores (2002).

Kinetic parameters	0.930	0.940	0.950	0.960	0.970	0.980	0.990
Λ_{GS}	1.62603E−03	1.60399E−003	1.58284E−03	1.56306E−03	1.54407E−03	1.52618E−03	1.50930E−03
Γ_{GS}	6.96697E−02	5.96893E−02	4.96521E−02	3.97795E−02	2.97903E−02	1.98512E−02	9.92636E−03
α	1.00960E+00	1.00917E+00	1.00896E+00	1.00895E+00	1.00914E+00	1.00951E+00	1.01005E+00
β_1^{GS}	2.32276E−04	2.32262E−04	2.32255E−04	2.32255E−04	2.32261E−04	2.32273E−04	2.32291E−04
β_2^{GS}	1.35850E−03	1.35848E−03	1.35847E−03	1.35847E−03	1.35848E−03	1.35850E−03	1.35852E−03
β_3^{GS}	1.09748E−03	1.09737E−03	1.09732E−03	1.09732E−03	1.09737E−03	1.09746E−03	1.09760E−03
β_4^{GS}	2.80567E−03	2.80580E−03	2.80587E−03	2.80587E−03	2.80581E−03	2.80569E−03	2.80552E−03
β_5^{GS}	8.38913E−04	8.38917E−04	8.38920E−04	8.38920E−04	8.38918E−04	8.38914E−04	8.38909E−04
β_6^{GS}	1.73161E−04	1.73165E−04	1.73166E−04	1.73166E−04	1.73165E−04	1.73162E−04	1.73158E−04
β^{GS}	6.50600E−03	6.50600E−03	6.50600E−03	6.50600E−03	6.50600E−03	6.50600E−03	6.50600E−03

Table 3
Kinetic parameters by Dulla et al. (2006).

Kinetic parameters	0.930	0.940	0.950	0.960	0.970	0.980	0.990
Λ_D	1.51958E−03	1.51317E−03	1.50758E−03	1.50295E−03	1.49917E−03	1.49632E−03	1.49439E−03
$\rho_{D,0}$	−6.51252E−02	−5.63223E−02	−4.73001E−02	−3.82555E−02	−2.89273E−02	−1.94641E−02	−9.82878E−03
q_D	6.51252E−02	5.63223E−02	4.73001E−02	3.82555E−02	2.89273E−02	1.94641E−02	9.82878E−03
β_1^D	2.33428E−04	2.35531E−04	2.37741E−04	2.40006E−04	2.42393E−04	2.44863E−04	2.47424E−04
β_2^D	1.30779E−03	1.31979E−03	1.33218E−03	1.34487E−03	1.35822E−03	1.37202E−03	1.38633E−03
β_3^D	1.15554E−03	1.16592E−03	1.17684E−03	1.18806E−03	1.19989E−03	1.21214E−03	1.22485E−03
β_4^D	2.49671E−03	2.51934E−03	2.54303E−03	2.56725E−03	2.59269E−03	2.61894E−03	2.64609E−03
β_5^D	7.85669E−04	7.92772E−04	8.00220E−04	8.07844E−04	8.15861E−04	8.24144E−04	8.32721E−04
β_6^D	1.59556E−04	1.61000E−04	1.62513E−04	1.64062E−04	1.65689E−04	1.67370E−04	1.69110E−04
β^D	6.13889E−03	6.19436E−03	6.25253E−03	6.31209E−03	6.37474E−003	6.43947E−03	6.50652E−03

subcritical systems, characterized by different effective multiplication factors (k_{eff} = 0.930; 0.940; 0.950; 0.960; 0.970; 0.980; 0.990) with external neutrons source constant in time and power ratio ($T(t) = e^{0.12353t} + 1$) will be presented in Section 5. The paper conclusions will be presented in Section 6.

2. Inverse kinetics equation for ADS reactor from the set of point kinetics equations proposed by Gonçalves et al.

Gonçalves et al. (2015) presented a new point kinetic model for ADS subcritical nuclear reactors based on the concept of the Heuristic Generalized Perturbation Theory (HGPT) importance function. The proposed importance function is related to the system subcriticality, with the value of the neutrons external source, represented by the following equation:

$$L_0^+\Psi_G^*(\vec{r},E,\hat{\Omega}) = F_0^+\Psi_G^*(\vec{r},E,\hat{\Omega}) - \frac{\rho_{sub}}{w_{source}}\nu(E)\Sigma_f(\vec{r},E,t_0)\int_{4\pi}\int_0^\infty \times \frac{\chi(E')}{4\pi}\hat{\varphi}_0^*(\vec{r},E',\hat{\Omega}')dE'd\hat{\Omega}' \quad (1)$$

where $s_0(\vec{r},E,\hat{\Omega})$ is the neutron source and

$$w_{source} \equiv \int_V\int_{4\pi}\int_0^\infty \hat{\varphi}_0^*(\vec{r},E,\hat{\Omega})s_0(\vec{r},E,\hat{\Omega})dEd\hat{\Omega}d^3r \quad (2)$$

The set of equations presented by Gonçalves et al. (2015) is:

$$\Lambda_G\frac{dT_G(t)}{dt} = \{\rho_G(t) - \beta_G\}T_G(t) + \sum_{i=1}^{6}\lambda_i\xi_i^G(t) + \Gamma_G T_G(t) + q_G(t) \quad (3)$$

and

$$\frac{d}{dt}\xi_i^G(t) = \beta_i^G T_G(t) - \lambda_i\xi_i^G(t), \quad (4)$$

where:

$$\Lambda_G \equiv \frac{1}{I_{F_G}}\int_V\int_{4\pi}\int_0^\infty \Psi_G^*(\vec{r},E,\hat{\Omega})\frac{1}{v(E)}\varphi_0(\vec{r},E,\hat{\Omega})dEd\hat{\Omega}d^3r \quad (5)$$

$$\rho_G(t) \equiv \frac{1}{I_{F_G}}\int_V\int_{4\pi}\int_0^\infty \Psi_G^*(\vec{r},E,\hat{\Omega})\{\delta F - \delta L\}\varphi_0(\vec{r},E,\hat{\Omega})dEd\hat{\Omega}d^3r \quad (6)$$

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