METHODS OF DELAYED NEUTRON FRACTION (β_{eff}) DETERMINATION IN TRAINING REACTOR VR-1

S. Michálek*,. Števo, G. Farkas*, J. Haščík***

Abstract: The aim of this work is to provide a theoretical background for the first measurement of delayed neutron fraction (β_{eff}) of VR-1 training reactor using in-pile kinetic technique. β_{eff} is determined from the transfer function obtained from simulations of reactor response to periodical reactivity insertion, using genetic algorithms for fitting the reactor response function. The final value of β_{eff} was determined to be 0.006664. MCNP5 calculations of β_{eff} for the model of VR-1 reactor using several cross-section libraries are also presented here. All these β_{eff} values have to be verified by measurements yet to be performed, to assess the theoretically estimated β_{eff} value of 0.00714, currently used by VR-1 reactor operators.

Keywords: delayed neutron fraction (β_{eff}), reactor transfer function, frequency response, genetic algorithms, monte carlo

MEASUREMENTS PERFORMED ON TRAINING REACTOR VR-1

The method for our measurement of β_{eff} on VR-1 training reactor at CTU in Prague is in-pile kinetic method. This method is based on sinusoidal (and trapezoidal) reactivity of ±0.05$ (and ±0.11$) insertion to a critical reactor by periodical movement of the control rod and following power oscillation measurement (Fig. 2). The reactor initial power was 1W (1.10^5 counts/s), i.e. zero-power. The power oscillations were measured by 4 fission chambers (power measurement during operation) and also by two ^{3}He detectors. 36 measurements were performed with oscillation period $20.25 \div 300$ s for ±0.05$ ($40.5 \div 300$ s for ±0.11$) reactivity insertion. Minimal oscillation period T_{min} reached by sinusoidal oscillation of control rod R1 was 20.25 s ($\omega = 0.31 rad/s$). This period is not suitable for determination of β_{eff} by none of previously mentioned frequency response areas, because $\omega = 0.31$ rad/s is not much lesser than $\lambda_{i\,min} = 0.0127\ s^{-1}$ and not much greater than $\lambda_{i\,max} = 3.87\ s^{-1}$ (Kropík et al, 2003). In the range of measured periods, none of the approximations could be applied. It was impossible to fit the reactor response for slow reactivity insertions, because it led to an important increase of reactor power mean value (unstable system). On the other hand, the minimal reached period was not small enough to come under the area of intermediate changes. Therefore, measurements with oscillation period of 1s and less are needed to reach this area, where $G_0(s) \approx 1/\beta$.

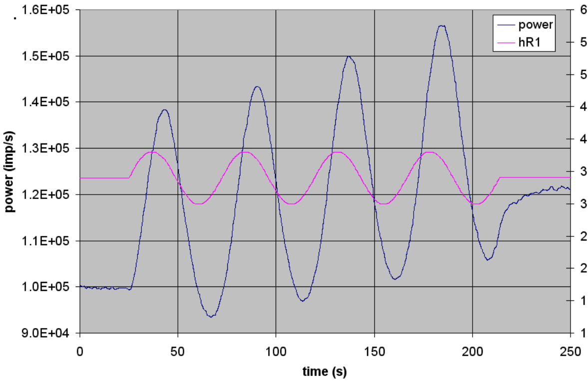

Fig 2 Reactor response (blue) to sinusoidal reactivity insertion (purple)

1.1 *Experimental results and data analysis*

By fitting the reactor response function (reactor power as function of time) it is possible to obtain the zero-power reactor transfer function in polynomial form. Response and transfer function of VR-1 reactor for oscillation period 22.5 s is depicted on Fig. 3.

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[*] Slovak University of Technology, Faculty of Electrical Engineering and Information Technology, Department of Nuclear Physics and Technology, Ilkovičova 3, 812 19 Bratislava, , E-mail: svetozar.michalek@stuba.sk

[**] Slovak University of Technology, Faculty of Electrical Engineering and Information Technology, Institute of Control and Industrial Informatics, Ilkovičova 3, 812 19 Bratislava. E-mail: stanislav.stevo@stuba.sk

Reactor power and R1 position values were set to the axes origin [0;0], therefore the power oscillates to negative values.

Transfer function was obtained using ARMAX model in numerical computing program MATLAB. In order to get more precise fitting of response function and subsequently more precise transfer function, the oscillation period has to be significantly lower. Its value should be ~1 s. Since the mechanical constraints of common regulating rods do not enable such short oscillation period, use of a device with a piston containing neutron absorbing material as the oscillation generator is required. This is essential to in order to resolve the shortest-living delayed neutrons precursors (Yedvab et al, 2006).

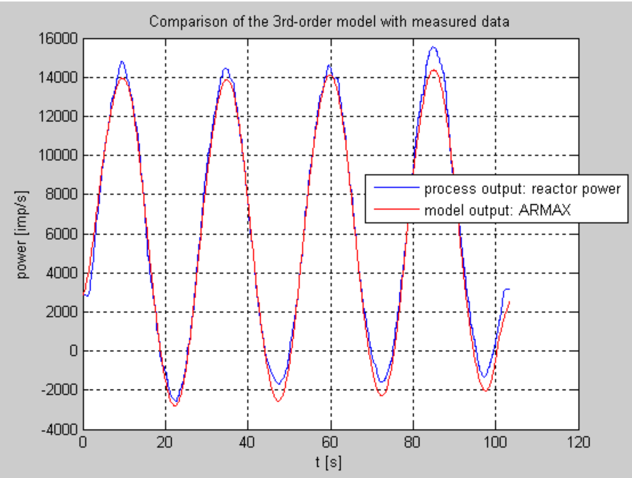

Fig 3 VR-1 reactor response (blue) and transfer function (red) for 22.5 s oscillation period

2 GENETIC ALGORITHM

Genetic algorithm (GA) is a heuristic method, which main objective is the effort to find the solution of complex problems (for which exact algorithm does not exist) by application of principles of evolution biology (Vose, 1999). Genetic algorithms and all methods which belong to evolution algorithms use techniques which imitate the processes of evolution, well-known in biology – heredity, mutation, natural selection and crossing (Sekaj, 2005).

The GA is based on consecutive production of various solutions for a given problem. During the process run, so-called *population* is kept. This population consists of terms and each term is one solution of given problem. As the population goes through the evolution, the solutions get better. Usually, the solution is represented by binary numbers, but it can be also found in other form (tree, field, matrix, etc.). At the beginning of GA (in the first generation), a population comprised of completely random terms is created and moving to the new generation, so-called *fitness* for each term is calculated. This fitness represents the quality of solution expressed by the resulting terms. According to this quality, the individuals are selected (by stochastic, random or another type of the selection). Consequently, they are modified (by mutation and crossing), and new population is created. This procedure is repeated iteratively and terminated either obtaining desired quality of the solution or elapsing a given time.

2.1 Process of Genetic Algorithms creation

Main goal of the process is Genetic algorithm, able to find the best parameters of transfer function (TF), which represents the measured object. In general, the structure of TF (degree of denominator - DoD) is not known in advance. The process of genetic programming algorithm (GP) creation is harder than that of genetic algorithm (Kvasnička, 2000). It is caused by the fact that for GP a specific toolbox for each task needs to be created; on the contrary, if we had toolbox for GA it should be easily used for many similar tasks. A mentioned fact has been solved (task for GP instead of GA) prescribing the structure of TF (degree of denominator). By considering this assumption, the task has been transformed from GP to GA (if the result does not satisfy the prescribed quality, GA is easily modified to another TF structure).

Structure of string

As mentioned before, the length of a string depends on TF structure. The genes represent the parameters of TF $a_0 \div a_{n-1}$ and $b_0 \div b_{n-1}$ (see Eq.(9)). If Dod is set to 3, it is obvious that amount of searched parameters is 6, if DoD is 4 than it is 8, etc. (The range of each parameter as an interval was set, i.e.: <-100, 1000>)

$$TF_{exmple} = \frac{b_{n-1}s^{n-1} + \ldots + b_1 s + b_0}{s^n + a_{n-1}s^{n-1} + \ldots + a_1 s + a_0} \qquad (9)$$

Size of population

The size of population depends on the amount of searched parameters. The population size is always four times bigger than the amount of mentioned parameters.

Mutation

Proposed GA uses two types of mutations. The first is the mutation on random value from given interval (with ratio 0.25) and the second is additive mutation (with the same rate). The rate – amount of mutations in one generation is normalized to interval <0, 1> bigger number stands for frequent mutation occurrence.

Crossing

In the algorithm, on point crossing was used and crossed strings were selected randomly.

Fitness

Fitness (quality of solution) is determined as sum of absolute values of difference between real (measured) data and data calculated in according to TF.

Conditions of termination

GA can work in two modes; it means that we defined two conditions of GA termination

- after reaching prescribed amount of generations
- if the value of fitness is stable for prescribed amount of generations

Syntax of GA

Mentioned GA was created in MATLAB, due to many advantages (matrix counting, etc.) of this program. The most important reason for using this tool is the existence of toolbox which involves basic functions needed for GA. This toolbox was created at our department.

3 CONCLUSION

Genetic algorithm seems to be a suitable tool for delayed neutron fraction determination using in-pile kinetic method based on periodical reactivity insertion to a critical reactor of zero-power. Simulations of such experiment by numerical computing program Bokin2000 with subsequent analysis in MATLAB provided a final value of effective delayed neutron fraction: β_{eff} = 0.006664. The precision of this value depends not only on the fitting technique, but also in the case of simulations, on the selection of the delayed neutron group parameters and it usually represents an idealized state.

The MCNP5 calculations confirmed the fact that the ENDF/B.VII library is more precise in β_{eff} calculations than its older B.VI version. The JENDL3.3 β_{eff} value for the VR-1 training reactor was calculated to be 0.007818±0.00010, which considerably exceeds the value of 0.006664 simulated by Bokin2000 program.

Therefore, a series of β_{eff} in-pile kinetic measurements is planned to verify these β_{eff} values and to assess, weather the estimation of the currently used β_{eff} value of 0.00714 was true.

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