REAL TIME ANALYZER FOR INVERSE KINETICS ROD DROP EXPERIMENTS*

Margarita K. Churchich**, J. E. Mott, J. C. Robinson,
and K. R. Piety(UT)

The University of Tennessee
Knoxville, Tennessee 37916
Telephone No.: 615/974-5048

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**Present Address: Biology Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830.

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Summary

A system is described that measures subcritical reactivity in nuclear reactors by the Inverse Kinetics Rod Drop (IKRD) technique. The analyzer was used in a large scale reactivity experiment performed in the Fast Flux Test Facility (FFTF) engineering mock-up core loaded in the ZPR-9 at Argonne National Laboratory.

The hardware used in the system included (1) a computer operating in a real time environment, (2) an interface to condition the signals from seven neutron sensors located in the reactor core and to transfer them into the computer at fixed time intervals (provisions were made to interface signals from individual neutron detectors operating in either the current or the pulse mode of operation), and (3) a cassette tape recorder for permanent storage of the raw data.

This system performs the following functions:

- (1) Examination of data from a preselected neutron sensor during the steady state operation to determine when the transient (rod drop) begins,
- (2) Simultaneous acquisition and storage of data from all sensors once the test is in progress,
- (3) Solution of the inverse kinetics equation for each of the seven sensors in real time by the three point method, and
- (4) Display of significant results immediately after the conclusion of the test.

The system allows the operator to determine the reactivity condition of the reactor immediately.

Introduction

A system was developed to measure subcritical reactivity in nuclear reactors in a real time environment¹. This system processes parallel data from seven sensors. Previous systems either processed the data off-line or had fewer channels and used a larger central processing computer.

This paper outlines the theoretical approach used in reactivity measurements and describes the hardware and software utilized to develop the real time analyzer.

Calculation Procedure

The Inverse Kinetics Rod Drop Technique utilizes the transient behavior of the neutron density following a step change in reactivity (a rod drop) to determine the values of reactivity before and after the drop. Figure 1 illustrates the behavior of the count rate (proportional to neutron density) during such a transient. The reactor is initially at steady state with reactivity ρ^*_i , and the count rate exhibits a constant mean value with inherent statistical fluctuations. At time T_0 the rod is dropped, and at T_1 (a few hundred milliseconds later) the rod is seated and the reactivity is constant (ρ^*_f). The measured values of the count rate are used to determine both ρ^*_i and ρ^*_f as well as the source strength (S^*).

The time-dependent behavior of a subcritical reactor is described by a normalized version of the point kinetics equations:

$$\frac{\lambda}{\beta} \frac{dn}{dt} = (\rho^* - 1) N + \sum_{i=1}^m \frac{\beta_i}{\beta} K_i + S^* \quad (1)$$

and

$$\frac{dK_i}{dt} = \lambda_i N - \lambda_i K_i, \quad (2)$$

where

m = number of delayed neutron groups (24 in this study),

N = number of counts recorded in 0.1 sec (proportional to the neutron density, n),

β_i = fractional yield of precursors of delayed neutrons for group i ,

ρ^* = reactivity, in dollars ($= \frac{\rho}{\beta}$),

λ_i = decay rate of precursors of the i th group, in sec^{-1} ,

K_i = normalized i th precursor group concentration ($= \frac{\lambda_i C_i \Lambda_c}{\beta}$),

S^* = normalized effective external source ($= \frac{S_0 \Lambda_c}{\beta}$),

Λ = prompt neutron generation time, in sec, and

= proportionality factor ($= n/N$).

Integrating both sides of Equation (2) between t and $t + \Delta t$ yields

$$K_i(t + \Delta t) = K_i(t) e^{-\lambda_i \Delta t} + \bar{N} (1 - e^{-\lambda_i \Delta t}), \quad (3)$$

where $K_i(0) = n(0)$ and $\bar{N}$ is the weighted mean number of counts obtained between t and $t + \Delta t$. Equation (3) provides a recursive relation for the i th precursor group.

The Three Point Method² is used to obtain real time results from all seven sensors. In Equation (1), β_i and β are known, N is obtained directly from the readings of the sensors, and K_i can be calculated from Equation (3).

The unknowns are ρ^* and S^* . Assuming the term on the left side of Equation (1) to be insignificant compared to the other terms ($\Lambda \approx 10^{-7}$ sec) and integrating Equation (1) over time intervals T_1 to T_2 and T_2 to T_3 (see Fig. 1), we obtain a system of two equations with two unknowns,

$$(\rho^*_f - 1) \int_{T_1}^{T_2} \lambda dt + S^* (T_2 - T_1) = - \int_{T_1}^{T_2} \left(\sum_{i=1}^m \frac{\beta_i}{\beta} K_i \right) dt \quad (4)$$

and

$$(\rho^*_f - 1) \int_{T_2}^{T_3} \lambda dt + S^* (T_3 - T_2) = - \int_{T_2}^{T_3} \left(\sum_{i=1}^m \frac{\beta_i}{\beta} K_i \right) dt. \quad (5)$$

Solving Equations (4) and (5) for ρ^*_f and S^* , the reactivity before the rod drop (ρ^*_i) can now be determined:

$$\rho^*_i = - \frac{S^*}{\lambda(0)}. \quad (6)$$

Then the instantaneous values of the reactivity for a single preselected sensor are evaluated from

$$\rho^* (t) = 1 - \frac{1}{\lambda(t)} \sum_{i=1}^m \frac{\beta_i}{\beta} K_i (t) - \frac{S^*}{\lambda(t)}. \quad (7)$$

Hardware

The overall system arrangement is shown in Figure 2.

A PDP-11/20 minicomputer (Digital Equipment Corporation), with 8K of memory, four DR11-C digital interfaces, an A11 digital-to-analog (D/A) converter, and a KE11/A for integer multiplication and division and for multiple shift operations, was chosen. The Tennecomp Systems TP-1371

MiniDek four-track cartridge magnetic tape recorder was used for the storage of the program that performed the experiment and also for the storage of the data during the real time phase of the test. A 7004B X-Y Plotter made by Hewlett-Packard was used for plotting. This analog recorder was interfaced with the digital computer through a digital-to-analog converter.

An interface was designed to provide timing, scale the data, accumulate the counts from the seven sensors, and strobe the data into the computer. Figure 3 presents the circuits used for timing, scaling and control. The one-shot generates a 50 nsec pulse at 100 msec intervals. This pulse stops the counters and interrupts the computer. Once all counters are read (40 μ sec later) they are reset and counting begins anew.

Since the number of counts from the sensors could be higher than 2^{15} , the data were scaled prior to transmission to the computer, allowing count rates up to 10^7 cps. The output buffer of the DR11-C controlled the scaling of the data coming into the counter (Fig. 3). If a bit was held high, the NOR gate to which it and the data line were attached was disabled, and the corresponding flip-flop (which divided the count rate by two) was enabled. The scale factors were set during steady state.

Four DR11-C General Device Interfaces were needed for this design, three controlling two channels each (Fig. 4) and the fourth controlling one channel and the logic of the circuit (Fig. 3). Channels 1 through 6 were connected to multiplexers (Fig. 4) while channel 7 was connected directly to the fourth DR11-C.

Software

The processing is segmented into five sections, which correspond to five different time periods of the test: (1) an initialization period, (2) a steady state operation, (3) a rod drop test period, (4) a transient real time operation, and (5) a final period in which results are presented.

(1) During the initialization period the test identification is entered, the data tape is rewound (≈ 6 minutes), and the sensor whose reactivities are to be presented in detail in the final period is chosen.

(2) During the steady state period, the scale factors are set to obtain maximum significance without overflow. Although the reactor is at steady state, the count rate exhibits statistical fluctuations. Thus, during the steady state period, the mean (μ) and the standard deviation (σ) of the count rate are calculated for each of the seven data channels. At approximately 20 seconds before the drop, the tape drive is started and the incoming data are stored serially on the tape.

(3) In order to determine the occurrence of the rod drop, the quantity $(\mu - \sigma)$ for the preselected channel is compared with the incoming data from that channel. When 40 consecutive readings show that the count rate is less than $(\mu - \sigma)$, the drop is assumed to have occurred and the first reading is taken as the point where the rod drop took place.

(4) The algorithm then begins the real time phase. Equation (3) is solved for each channel at every t_j , and the integrals required for the solution of Equations (4) and (5) are constructed. This phase of calculation is carried out for 4 minutes after the drop, when it is considered that the real time phase is terminated. These calculations are performed concurrently

with the data acquisition and data storage on tape utilizing the multiple priority interrupt structure of the PDP-11 to accomplish these parallel operations. Once the test is terminated, the values of ρ_f^* and S^* for each of the seven sensors are determined by simultaneous solution of Equations (4) and (5), and the initial reactivities ρ_i^* are calculated using Equation (6). The essential results of the test have now been obtained and the computation proceeds to the final phase.

(5) In this portion of the operation the test results are presented and compared to the theoretical values. Equation (7) is solved for instantaneous values of the reactivity, using values stored in core for the channel selected in the initialization period.

Results

Numerical results from a typical rod drop test are presented in Figure 5. The reactivities for the preselected channel are plotted as a function of time as shown in Fig. 6. The values of the count rates obtained by theoretical means are plotted and compared to the values in the test (Fig. 7).

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References

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Figure 1
Count rate behavior during an IKRD experiment

CONTROL LOGIC

Scaling Circuit

DATA FROM DRHC-4

BLE A (Channels 1,2,3 & 4)

Channels 5,6 & 7

→ RESET 2

→ RESET 1

→ RESET 4

→ RESET 3

→ RESET 6

→ RESET 5

→ RESET 7

Clock Rate $\approx$ 100 ms
Time to Readout Data $\approx$ 40 μ s

2

DATA TO
TO DRIM

ANSWERS BY USE OF 3 POINT METHOD
 INITIAL TIME AFTER DROP= .60000000E 1
 SECOND TIME POINT= .25000000E 3
 FINAL TIME POINT= .24000000E 4
 SOURCE EST= .10313971E 6 (Channel 1)

.10313732E 6 (Channel 2)
 .10313957E 6 (Channel 3)
 .10313807E 6 (Channel 4)
 .52475554E 4 (Channel 5)
 .52474756E 4 (Channel 6)
 .10308217E 6 (Channel 7)

Channel for source iteration: 1
 Expected values: $\rho_f^* = -2.29$

$\rho_1^* = -1.15$

FINAL REACTIVITY=-.22781714E 1

-.22781210E 1
 -.22781685E 1
 -.22781361E 1
 -.39606647E 0
 -.39605981E 0
 -.22758126E 1

INITIAL REACTIVITY=-.11770178E 1

-.11769904E 1
 -.11770161E 1
 -.11769990E 1
 -.23953784E 0
 -.93990248E 0
 -.46158952E 1

DO YOU DESIRE TO PRINT REACTIVITIES?

REACT FROM SOURCE CALC

-.11877175E 1 (ρ_1^*)
 -.12342376E 1 (ρ_2^*)
 -.13820492E 1
 -.16836147E 1
 -.20510771E 1
 -.22603755E 1
 -.22995142E 1
 -.22837692E 1
 -.22772683E 1
 -.22789370E 1

⋮
 -.22691090E 1
 -.22692448E 1
 -.22685924E 1
 -.22631098E 1
 -.22906841E 1
 -.22822839E 1
 -.22584533E 1
 -.22532285E 1
 -.22977785E 1 (ρ_{130}^*)

Reactivity
(dollars)

-1.25

-1.50

-1.75

-2.00

-2.25