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MASTER

COMPUTER APPLICATIONS IN SIMULATION

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COMPUTER APPLICATIONS IN SIMULATION

The subject of this paper deals with simulation by electronic computers. It may be well to relate this to other computer uses and to computers in general. Computer usage can be roughly divided into the categories of accounting uses and scientific or engineering uses.

The area of accounting which includes payroll, inventory, and bookkeeping is probably of little interest to an engineer unless he decides to enter the field of programming or of equipment development. By programming is meant the writing of computer codes that allow the machine to make use of certain capabilities or to perform specified functions. The accounting aspects of computer usage are dominated by digital machines.

The engineering and scientific uses of computers cover equation solving, simulation, process control, design optimization, and others. The computer is one of the tools available to the engineer to aid in problem solving. The engineer has two basic types of computers available for his use, the digital computer and the analog computer.

When using a digital machine, an engineer will generally use a compiler language and "talk" to the machine by means of symbols and equation notation. This language is then converted to a machine program which the computer uses to actually perform the calculations. If an analog computer is used, the problem is programmed by means of patch-cords that interconnect the computing elements in the manner specified by the equations.

Equation solving implies a set of equations which define a state or condition. When the numbers and conditions are supplied, the computer

program produces the answer. This can be enlarged to include answers for many specified conditions.

Process control is the use of a computer to observe the action of a process variable. As the variable changes, the computer supplies a calculated value that is used to maintain the observed variable within specified limits.

Simulation is when a computer model of a dynamic system is used to check pertinent conditions and responses for the actual system. Simulation has wide spread use in all engineering disciplines.

It is within the area of simulation using electronic analog computers that the following examples are given.

ANALOG SIMULATION OF HANFORD DUAL PURPOSE REACTOR PLANT

An analog simulation of the dual purpose Hanford N-reactor was prepared. Studies were performed to determine the dynamic characteristics of the plant and to determine the effects of possible plant, operator, and control system malfunctions. Various operational procedures and proposed design changes were also studied.

The simulation of the reactor plant was made up of a series of subsystems which were coupled together. Each subsystem had been studied in detail previous to being assembled into the total reactor plant simulation.

Analog studies showed that it was possible to predict dynamic characteristics resulting from spurious transients such as reactor scrams and component failures. In addition, study of system control methods revealed certain desirable modifications to the reactor primary coolant and secondary heat dissipation system. Approximate controller settings

were determined, by use of the simulation, which increased the stability of both the primary and secondary systems. ~~In this paper, which is a progress report,~~ ^{concluded} It is shown that an entire reactor plant, including a heat dissipation system, can be successfully simulated and that simulation results are useful as guidelines in complex plant operation and control.

Plant Description

The N-reactor plant system consists of a group of interconnected subsystems. The complete plant is divided into two flow loops, a primary coolant system, and a secondary heat dissipation system (Figure 1). The common medium between the two systems is the steam generator where reactor heat is transformed to steam which will operate the electrical generation plant and auxiliary equipment.

The primary coolant system is made up of the reactor, primary side of the steam generator, and the primary coolant pumps. The reactor has a graphite-moderated, water-cooled core with horizontal process tubes. These tubes house both the fuel and coolant water. There are five primary pump loops which feed headers supplying coolant to risers that connect to the process tubes. The prime movers used to circulate water through the primary coolant piping are steam-driven turbine-pump combinations.

The secondary heat dissipation system consists of the secondary side of the steam generators, a system of steam surface condensers known as dump condensers, a condensate surge tank, and condensate feedwater pumps. The steam generators are shell-and-tube single pass heat exchangers. Each primary pump loop contains two steam generators. Condensate

HANFORD DUAL-PURPOSE N-REACTOR SCHEMATIC

FIGURE 1

feedwater flow to the steam generator is controlled by feedwater control valves operated from steam generator water level. The dump condensers condense ~~any~~ excess steam not used by the electrical generating plant or auxiliary steam loads. The 16 dump condensers have the capacity to dissipate the entire heat capability of the reactor during normal operation. The condensing rate in the dump condensers is controlled by the amount of condensing area available which is a function of the water level. The main steam header pressure setpoint and the condensate suction header-main steam header differential pressure setpoint control the level of water in the dump condensers.

The condensate surge tank serves to maintain secondary water inventory and secondary condensate pressure. Normal fill valves are controlled by the normal surge tank water level. Extremes in surge tank level actuate emergency fill and spill valves. Steam pressure in the main steam header, which is the steam distribution point, is maintained by butterfly control valves supplying the dump condensers. These valves will operate in conjunction with another set of butterfly control valves supplying the electrical generating plant when that plant is in operation.

The basic control of the reactor plant is accomplished by the usual two or three mode controllers. For example, the steam generator water level control employs both proportional and proportional-plus-integral control. Also, control of the primary coolant pumps employs proportional-plus-rate-plus-integral control.

Purpose of the Simulation

The purpose of the N-reactor plant analog simulation was to study the dynamic characteristics of each subsystem as well as the dynamics

of the complete integrated system. The simulation was used as a tool to show trends in the physical system dynamics. Approximate values for controller settings were also obtained from the simulation.

However, analog results were not expected to match precisely the results of similar transients in the reactor plant due to operator functions and the limited amount of automatic control used at the reactor during testing procedures.

RADIOISOTOPE I¹³¹ DISTRIBUTION IN MAN

An analog model of a biological system was made for the purpose of defining the distribution of radioisotopes in the body of man or animals for various types of radioisotopes and for various animals. It is desired to define the amount of radioisotopes and the time transients for possible methods of uptake of radioisotopes in the different compartments of the body including the lungs, stomach, small intestine, upper large and lower large intestines, skin, blood, kidneys, thyroid, bone, muscle and other organs as shown in Figure 2.

The simulation was set up with the compartments indicated with the capability of defining both a parent and a daughter radioisotope in each of the compartments. Provision is made for the uptake to be ingested into the stomach, inhaled into the lungs, absorbed through the skin, or injected into the blood or any combination as the particular investigation requires. Provision is made to show both parent and daughter radioisotopes with uptakes of the amounts of each in arbitrary quantities. The uptakes can be in single doses with one feeding, one injection, or one contact with the skin; or can be in multiple doses

FIGURE 2 - Compartmentation for biological radioisotope uptake

as though eating once or twice a day from either a constant or a decaying source of arbitrary quantities of both the parent and daughter radioisotopes. Also, any combination of uptakes can be included for study.

The system is described by differential equations, the coefficients of which are unique for particular types of animals and for particular combinations of radioisotopes. To change animal or radioisotope it is only required to change the coefficient potentiometers to new values. This, of course, presumes that the coefficients are already known.

Figure 3 shows an example for man of I^{131} ingestion from a decaying source. The rate of source decay is that of I^{131} with approximately eight days half-life. The feedings (Channel 1, Figure 3) are once a day with ten microcuries per feeding starting rate. The stomach shows less than ten microcuries because the feeding is not instantaneous and biological transfer to the blood takes place. Each major division on the time axis is five days. The second channel shows the quantity of I^{131} in the blood. The third channel shows the concentration in the upper large intestine and the fourth in the thyroid. It is of interest to note that the peak value in the thyroid is approximately 8.8 microcuries which occurs about 12 days after the beginning of intake. Channel 5 is a logarithmic plot of the quantity of radioisotope in the thyroid, and Channel 6 shows the amount of I^{131} in the bone. Channel 7 shows the amount of I^{131} in the muscle. Of interest in each of the traces is the peak amount and the time after beginning of ingestion at which the peak occurred.

Stomach

I^{131} ingestion once
a day from a MAN
decaying source
start at 10 microcuries (u.c)
per feeding

10/17/64
E.C. Watson
R.A. Harrel

Blood

→ ← 5 days

E.C. Watson
R.A. Harrel

Upper Large
Intestine

FIGURE 3

Thyroid

(Log₁₀)
Thyroid

Bone

Muscle

RIVER ROUTING

The ability to predict Columbia River flow rates at downstream points after changing upstream flow (raising or lowering gates at Priest Rapids Dam) is of interest to hydrologists for flood forecasting. Figure 4 shows typical plots of flow rates with time at the input and output of a river reach. Equation (1), which was derived from standard hydrology equations, is a mathematical model that describes outflow from a given section or reach of the river as a function of inflow.

$$\frac{dO}{dt} = \frac{I - O - pkx I^{p-1} \frac{dI}{dt}}{pk(1-x)O^{p-1}} \quad (1)$$

where,

I = river flow rate at input of river reach (a given function of time)
 k = a parameter (to be optimized)
 p = " " { " "
 x = " " { " "
 O = river flow rate out of section

The analog simulation computes the outflow by using Equation (1) and comparing the results with the outflow data shown in Figure 4. The difference (the error) was squared and integrated over the computation time and used as a performance criterion.

A measure of the partial derivative of the performance function with respect to each parameter was used to automatically adjust the parameters for the optimum fit of the computed curve to the measured curve. Figures 5 and 6 are photographs of oscilloscope tracings showing comparisons of the measured value of outflow with the computed value of outflow. The curve with the series of straight line segments shown in Figure 5 is the measured outflow and the smooth curve is the computed value. The

FIGURE 5. Photograph of Oscilloscope Tracing Showing Initial Fit

FIGURE 6. Photograph of Oscilloscope Tracing Showing Optimum Fit

values of x and k , initially chosen, produced a poor fit; however, the automatic optimization resulted in values of parameters with the close fit shown in Figure 6 in approximately 40 seconds.

WIND TURBULENCE DATA

Meteorological variables which are measured at Hanford to increase understanding of wind turbulence in the boundary layer of the atmosphere include wind speed and direction. A hot wire probe is used which transmits signals that vary as the wind speed (V), horizontal angle (θ), and vertical angle (ϕ). The vertical angle is measured with respect to ground (Figure 7). The signals representing V , θ , and ϕ from the probe are recorded on magnetic tape. Analog computation is used to transform the data from spherical to Cartesian coordinates and to perform a Fourier analysis which yields spectral data, showing the wind speeds and directions which are most prevalent.

The data recorded on magnetic tape at the Atmospheric Physics Laboratory is played back at the analog computing laboratory where the recorded signals representing V , θ , and ϕ are played from the magnetic tape playback unit into the analog computer where computation is completed to perform the coordinate transformation and to solve for the averages to give the quantities u , v , and w . The quantities u , v , and w are recorded simultaneously on another tape recorder after computation is performed which orients the Cartesian coordinate system so that u is in the direction of the mean wind velocity, and so that average $\bar{v}$ and $\bar{w}$ are zero. Figure 8 shows typical data for two time scales. Notice that $u - \bar{u}$, v , and w are centered around zero, while V_H has an average value of seven meters per second.

FIGURE 7. Spherical Coordinate System

FIGURE 8- TYPICAL WIND TURBULENCE DATA AND RESULTS

PRTR TRANSIENT STUDY

The operation of a reactor such as the PRTR in a manner different from previous operations is generally preceded by investigations of possible hazards resulting from the new method of operation. A raise in the operating power level of the Plutonium Recycle Test Reactor is being studied. An analog study was designed to determine the effects of various types of conceivable credible accidents at higher power levels.

An analog simulation of the PRTR kinetic equations was made using five groups of delayed neutrons, temperature feedback of reactivity, and provisions for simulating the reactor inputs associated with various conceivable accidents. Since many of the transients being studied occur during the startup phase of operation, it was necessary to design the simulation to operate over many decades of power. The analog simulation was programmed on the Beckman Model 2133 iterative computer to automatically range through as many decades as necessary.

Figure 9 shows a typical startup run for which reactivity increases at a rate of .28 mk per second and the scram level is set at 156 megawatts. Channel 1 records the reactor power level where automatic scale changes take place. The first excursion represents the reactor power level between 10 kw to 100 megawatts, and the third from 100 megawatts to 250 megawatts. Channel 2 shows the integrated power during each section of the run. Since this variable was automatically scaled, the total integrated power can be obtained from the last section of the run. Channel 3 shows the average fuel temperature and Channel 4 the average cladding temperature. Channels 5 and 6 show the maximum fuel and cladding temperatures and Channel 7 records the total reactivity associated with the reactor during the run. Of particular interest are the peak temperatures reached during the transient.

1 MW

100 MW

250 MW

POWER LEVEL

5000 MW/sec.

INTEGRATED POWER

2250°F

FUEL TEMP. (AVERAGE)

450°F

CLADDING TEMP. (AVERAGE)

4500°F

FUEL TEMP. (MAX.)

450°F

CLADDING TEMP. (MAX.)

-45 mk.

REACTIVITY (TOTAL)

0.28 mk/sec

0
+5 mk.

FIGURE 9
PRTR TRA
Scram at 156 MW.