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CONTROL LOOP AND UNIT OPERATIONAL REALTIME MODELING ON A DISTRIBUTED CONTROL SYSTEM (U)

by

K. Rueter

Westinghouse Savannah River Company
Savannah River Site
Aiken, South Carolina 29808

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CONTROL LOOP AND UNIT OPERATION REAL TIME MODELING ON A DISTRIBUTED CONTROL SYSTEM

Ken Rueter
DWPF Process Simulation Group
Building 706S
Savannah River Site
Aiken, South Carolina 29808

ABSTRACT

The Defense Waste Processing Facility (DWPF) will be primarily controlled by a Distributed Control System (DCS). The magnitude of the DWPF process requires that an ample amount of realistic and effective process and procedure oriented training take place on the DCS as a prerequisite for safe and efficient operation of the plant.

To help ensure that the training goal will be accomplished, the decision was made to develop a series of simulation packages that deal with selected sections of the process. These simulation packages are executed not on a mainframe computer, as is the usual case, but in the Distributed Control environment, the same DCS structure built to control the process.

This paper will provide a review of the advantages and disadvantages of this approach and an in-depth discussion on the development of the concept of "Functional Simulation" and how it was used to generate these DCS-oriented Process Simulation packages.

INTRODUCTION

One of the most difficult and time consuming tasks is preparing for the start up and operation of a one of a kind facility. The Defense Waste Processing Facility (DWPF) is exactly this type of process. The magnitude and configuration of DWPF is employed by no other facility. DWPF is a true "Grass Roots Facility".

The Defense Waste Processing Facility will be used to process liquid radioactive waste into a safe, stable and manageable form. The waste will be bound in a solid glass matrix for safe storage for thousands of years. The process will be primarily controlled by a Distributed Control System (DCS). The DCS will be responsible for the processing of the information from 6400 digital and analog I/O points. The processed information will be displayed to the operators via DCS consoles. The complexity, significance, and importance of DWPF along with the first time application of this process requires that an ample amount of realistic and effective process and procedure oriented training and testing take place.

Consequently, the decision was made by the DWPF Control and Information Systems group to develop a series of Process Simulation Packages that deal with major sections of the DWPF process. It is critical to the safe and efficient operation of the facility that the operators become familiar with the DCS and process control configuration,and proficient in the operation of the process. As a result, the simulation packages had to be executable in the DCS environment and provide a representative image of the process.

To minimize development time, manpower requirements, equipment needs, and simulation package unit costs, the decision was made not to add a mainframe computer to the DCS network to execute the simulation algorithms. Consequently, standard classical simulation concepts could not be utilized because the models have to be able to run on the DCS.

THE PROCESS

The DWPF process is composed of six main processing areas **(Fig 1).**

1) Primary Water System
2) Melter Feed Preparation
3) Glass Melter
4) Melter Off-Gas System
5) Precipitate Aqueous Processing
6) Process Ventilation System

DWPF utilizes a vitrification process to produce the glass compound. The initial sludge is processed to remove excess water and mercury before being fed to the Melter.

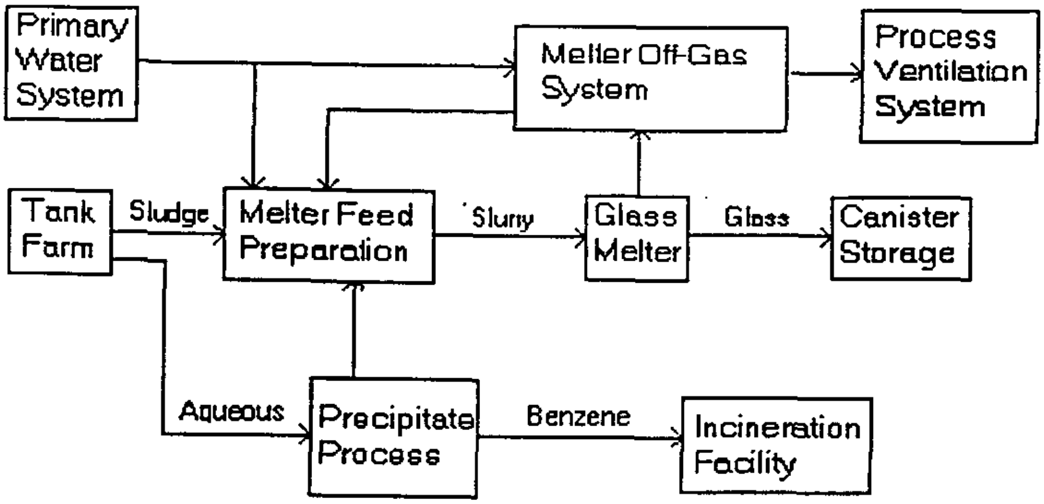


Figure 1: The sludge is fed from a storage tank to DWPF. The sludge is processed by the Melter Feed Preparation area into a glass frit slurry. The slurry is transformed into molten glass by the Melter and poured into Stainless Steel canisters that are welded shut. The vapor produced by the Melter is processed by the Off-Gas system. The Precipitate process removes organic material from the aqueous Melter feed.

THE DISTRIBUTED CONTROL SYSTEM

The DWPF DCS is composed of a DEC 11/750 computer (HOST), Operator Console Module (OCM), Process Control Module (PCM), and data network. The HOST is used for system configuration development and display generation. The OCM is the operators window to the process. The PCM houses the process controller and field equipment interface. The data network handles communication between the individual system components. **(Fig 2)**

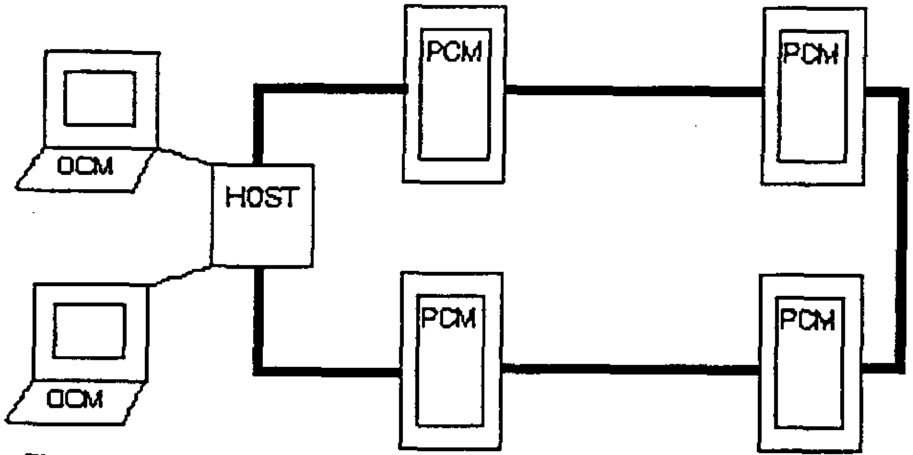


Figure 2: Defense Waste Processing Facility Distributed Control System structure.

The DCS utilizes a Function Block and Sequence language for configuring the system **(Fig 3)**. The capability to develop and execute "C" and Fortran programs on the DCS is available.


```
IF MOTOR1 = RUNNING THEN
   BEGIN
      OPEN VALVE2
      CLOSE VALVE1
      STOP PUMP7
      WAITUNITL FT1 = 300
   END
```

Figure 3: An example of the Distributed Control System's Configuration languages.

THE CONCEPT

Many different methods of process modeling are available for development of process simulations. The following is a list of techniques considered for the development of the DWPF Process Simulation Packages.

1) Linear Systems Programing

Process models are represented by linear equations using matrix solution methods.

2) Dynamic Simulation

Modeling of process values by simulating time versus the state of parameters being simulated. The models are represented by first and second order dynamic systems. An unsteady state image of the process parameter is generated in a real time condition .

3) Parameter Estimation Simulation

The implementation of a predefined model structure with adjustable parameters. The concept calculates the value of the parameters from response data for the process being modeled.

4) Unit Operation Modeling

The development of a model by integrating engineering design information and mass and energy balance techniques and/or concepts.

5) Control Loop Real Time Modeling

The model scans time to inspect the state of the model output that may be a function of time or the value of another variable.

The criteria for the DWPF simulation packages required that the concept(s) utilized must be capable of producing process models that can be developed and executed on the DCS. Secondly, the models must provide an accurate real time response to the DCS control and indication loops.

Each concept was reviewed with the intent of making the method the accepted standard for generating the DWPF process simulation packages. After reviewing the listed concepts, the simulation team came to the conclusion that not one of the individual concepts would satisfy the criteria for the packages.

However, it was quite clear that three serious limitations existed on the DCS and the concept would have to be flexible enough to overcome them without compromising the package criteria.

DCS SIMULATION LIMITATIONS

A) The DCS configuration does not provide a method for iterating toward a model solution.

B) The DCS's ability to solve differential equations is very limited. For example, the only numerical integration routine available is Eulers.

C) The DCS processes variables relatively slowly compared to a standard computer system.

From these limitations, it was concluded that the concept accepted as a standard method for developing the process models for the simulation packages would have to generate the models in a non-differential or analytical equation format.

By combining the concepts of Control Loop Real Time Modeling and Unit Operation Modeling , a technique was formulated which generates process models that conform to the requirements of the simulation packages and overcome the DCS simulation limitations.

The concept was titled "**Functional Simulation**"

This concept is used to develop model equations in an analytical form. The models resemble an input - output or Transfer Function model structure **(Fig. 4)** in which a dependent - independent variable relation is defined by the model.

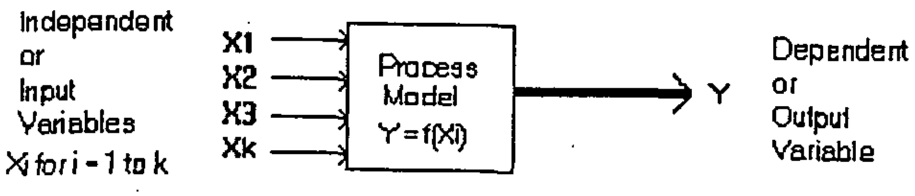


Figure 4: A Process Model represented in a "**Functional Simulation**" format.

From **figure 4**, the following functional relationship can be defined.

$$y = f(x1, x2, x3, \ldots xk)$$

It is important to point out that the independent variable will represent the position of a final control element , process load, process disturbances, etc. However, the dependent variable will always be the process or measured variable for the simulated loop.

CONCEPT APPLICATION

As previously mentioned, **"Functional Simulation"** is a combination of Control Loop and Unit Operation modeling techniques. The Unit Operation modeling concepts are implemented in the initial stages of model development to define the mass and energy balances for the process and provide a frame work for the dependent - independent variable relationship. The Control Loop modeling techniques are used to tailor the Unit Operation model into a format executable on the DCS.

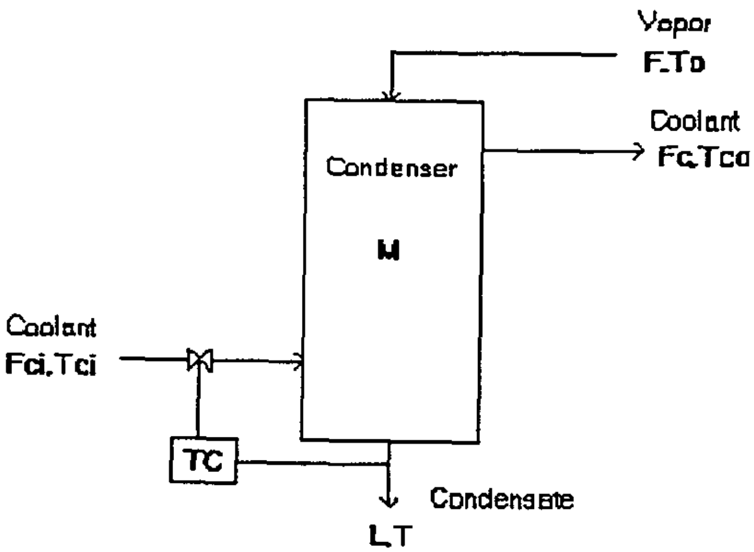
A sample application is shown in **figure 5**.

The first step is to develop a model in a differential equation format **(Fig. 5 Part I)** in which the number of degrees of freedom (n) can be determined. Since the number of degrees of freedom is greater then zero, the model is underspecified which means a unique solution does not exist **(Fig. 5 Part II)**.

At this point, the differential equations must be solved analytically or it must be assumed that the integration method available of the DCS is satisfactory for the application, for example, simple material balances **(Fig 5 Part III)**.

In order to calculate a unique solution for the model, the number of degrees of freedom must be reduced to zero There are three external sources available that can accomplish this task. 1) The Process Design Information, 2) The DCS Control Configuration or Loops, and 3) Other Process Models. The process design information provides empirical data, for example, heat capacities, mass transfer coefficients, surface areas, vessel volumes, etc. The DCS control loops provide a value for the manipulated or independent variable, for example, valve position, variable frequency drive setting, pump stroke length, etc. Other process models provide load and disturbance variable values to the model. By integrating these external sources into the Unit Operation model, the number of degrees of freedom is decreased to zero and a unique solution can be determined from the model **(Fig. 5 Part IV).**

By solving the differential and decreasing the number of degrees of freedom to zero , the model has been transformed into a format which can be implemented on the DCS **(Fig. 5 Part V).**



Tci = Coolant Inlet Temperature
T = Condensate Temperature
L = Condensate Flow
To = Gas Inlet Temperature
F = Gas Inlet Flow
M = Liquid Hold Up in the Condenser
Cp = Heat Capacity of the Gas
HVAP = Heat of Vaporization
Tco = Coolant Outlet Temperature
Cpc = Heat Capacity of the Coolant
Fc = Coolant Flow

I Energy Balance around the condenser

M * Cp * dT/dt = F * Cp * dT/dt + HVAP * L - Fc * Cpc * (Tco-Tci)

II Degrees of Freedom

n = number of variables - number of equations
n = 11 -1 = 10 degrees of freedom

III Model Simplifications

No liquid hold up M = 0.0

dT/dt = T - Tref

F=L Total Condensation

The addition of Tref increases the number of degrees of freedom to eleven. However, this is not a problem if a value for the variable can be identified.

IV Degrees of Freedom Reduction

Source	Variables Specified	Degrees of Freedom
Process Design Data	Cp, Cpc, Tref, HVAP, Tco, Tci	11 - 6 = 5
Other Models	To, F, L	5 - 3 = 2
Temperature Control Loop	T, Fci	2 -2 = 0

V Final Solution

T = ((Fc * Cpc * (Tco - Tci) - HVAP * L) / (F * Cp)) + Tref

Figure 5: Sample **"Functional Simulation"** Application

PROCESS SIMULATION PACKAGES

By developing a standard concept "**Functional Simulation**" which provided a means for model generation, it was possible to satisfy the criteria for the packages and receive area support for simulation.

The simulation packages provide a set of process models to a user which allows for the closure of a specific group of DCS loops so that a representative image of a specific processing area of DWPF is generated for both the operator and control configuration **(Fig 6).** As previously stated, the operator becomes more comfortable, familiar, and experienced with the DCS, and the control configuration is tested off-line with no risk to personnel or equipment.

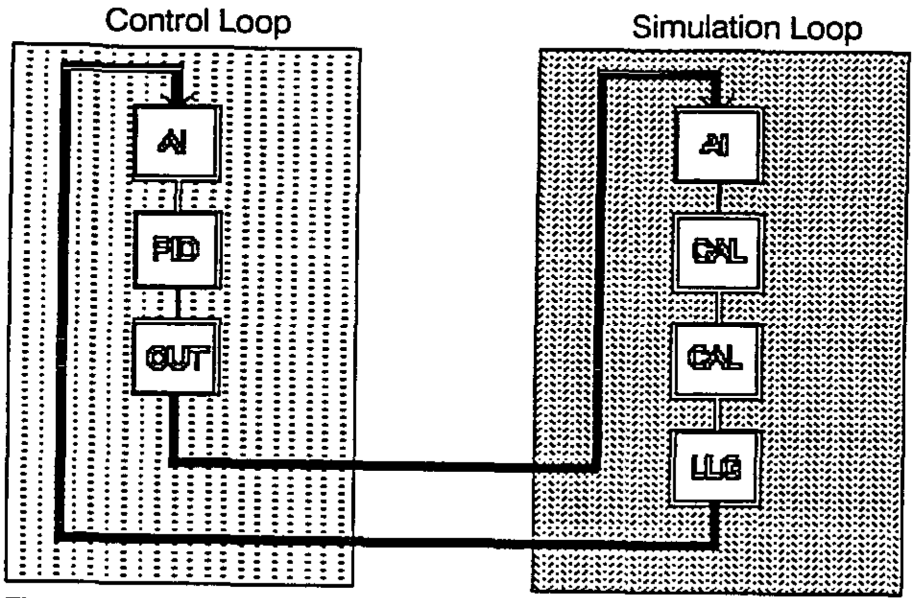


Figure 6: The link between the model and control configuration

PACKAGE STRUCTURE

A DWPF simulation package consists of three main sections, 1) Analog database, 2) *Digital or Discrete database, and 3) Supervisory* programs **(Fig 7).**

The analog database contains the algorithms for the process models and the corresponding control or indication loops. The *digital or discrete database* contains the code for the field device logic and the logic required to simulate the field device. The supervisory programs are used to initialize the packages, provide package statuses to the user, and as a means for user interface to the package.

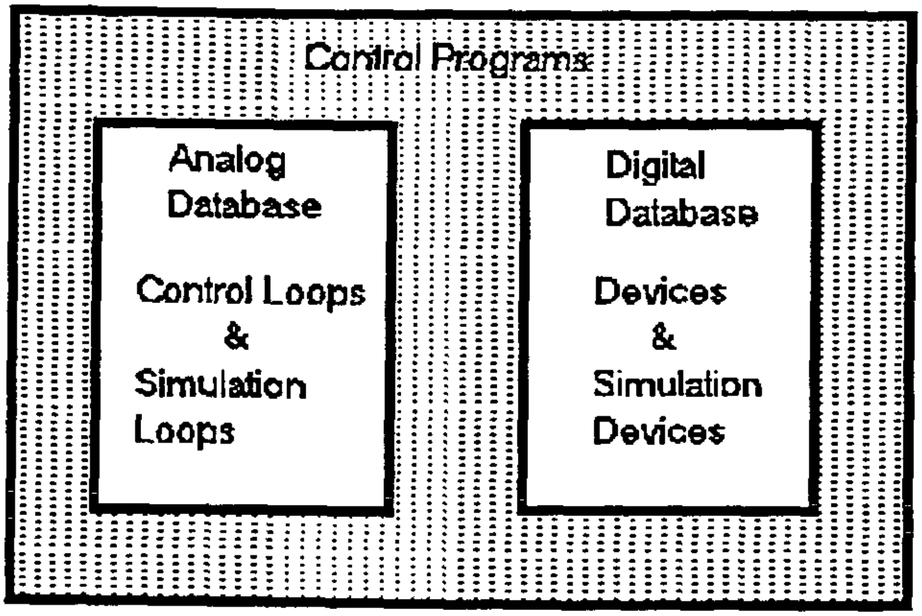


Figure 7: Process Simulation Package Structure

PROCESS SIMULATION PACKAGE APPLICATIONS

Although, the original intent of the Simulation packages was to provide a vehicle for operator training. Several other applications have been identified and implemented.

1) Regulatory Control Configuration Evaluation

2) Advanced Control Configuration Feasibility Analysis

3) Batch Process Sequence Testing

4) Automation Program Evaluation

5) Initial PID Controller Tuning Parameter Estimation

ADVANTAGES OF DCS "Functional Simulation".

By requiring that the simulations run on the DCS, several advantages were recognized over using a mainframe computer tied to the DCS.

1) Becuase the DCS configuration language is implemented in a block format, it allows engineers or engineering assistants to code and implement the model algorithms without the need for a strong programming background. Secondly, the communication link between the models and control configuration is easily established and requires no fancy programming techniques or exotic protocols.

2) It is not necessary to interface additional hardware to the existing DCS to execute the simulation packages.

3) The display and diagnostic utilities of the DCS are available to evaluate, trouble shoot, and enhance the simulation.

Based on the criteria for the simulation packages, the bottom line is that the overall unit cost per package is significantly less because the simulation is executed on the DCS.

DISADVANTAGES OF DCS "Functional Simulation".

As with any new concept or techique, some limitations are experienced.

1)The response of the models sometimes appears rough because of the slower processing times of the DCS.

2) Profitability analysis on the operation of the process can not be generated from the simulation.

3) The dynamic response of some models is compromised because of the inability of the DCS to solve differential equations or iterate toward a solution.

RESULTS

Presently, four complete simulation packages have been developed.

A) Primary Water System - this package simulates the processing of raw water from deep wells and its supply to the facility for domestic and process use.

B) Melter Feed Preparation - this package simulates the chemical adjustment, processing, and addition of frit to the tank farm sludge in preparation as feed to the Melter.

C) Emergency Power Distribution - this package simulates the switchover from normal to emergency power, the loading of the emergency power source, and positioning of electrical distribution breakers.

D) Melter Off-Gas - this package simulates the continuous processing of the vapor generated during Melter operation in preparation for discharge to the atmosphere.

Two of the packages (Primary Water System and Melter Feed Preparation) are being used to train , evaluate, and qualify the control room operators on the operation of the corresponding processes. The other two packages are being used by the start up groups for off-line analysis of sophisticated process automation programs before field implementation, testing, and verification.

The four packages were developed in an eighteen month time period. Five more packages are scheduled to be generated over the next two years.

Because of the success experienced on the DWPF simulation project, the DCS "**Functional Simulation** " concept is being considered for other projects at the Savannah River Site.

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