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Trip and Control System Models in SPACE Code

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1. Introduction

KOPEC has been developing a hydraulic solver of SPACE, which is a nuclear power plant safety analysis code, using two-fluid, three-field governing equations [1]. Several numerical schemes, such as collocated, staggered, semi-implicit, and implicit schemes, have been tried so far. In this paper, the trip and control system model of SPACE will be described. The trip system of SPACE is developed to evaluate logical statements. Each trip statement is a simple logical statement that has a true or false result and an associated variable. The control system provides the capability to evaluate simultaneous algebraic and ordinary differential equations. The capability is primarily intended to simulate control systems typically used in nuclear reactor systems, but it can also model other phenomena described by algebraic and ordinary differential equations.

2. Trip and control models

2.1 Trip System

Two types of trip statements are provided, variable and logical trips. Since logical trip involve variable trips and other logical trips, complex logical expressions can be constructed from simple logical statements. Both types of trips can be latched or unlatched. A latched trip, once set true, is no longer tested and remains true for the remainder of the problem or until reset a restart. An unlatched trip is evaluated every time step.

A variable trip evaluates the statement

$$T_{ri}=V_1 \text{ OP } (V_2+C) \qquad (1)$$

The value T_{ri} is the i-th trip variable that may true or false. V_1 and V_2 are quantities from the heat structures, hydrodynamics, reactor kinetics, control systems, or may be a TIMEOF quantity. The value C is a constant. The operation OP is one of the following arithmetic relational operations: EQ is equal, NE is not equal, GT is greater than, GE is greater than or equal, LT is less than, and LE is less than or equal.

A logical trip evaluates

$$T_{ri}= \pm T_{rj} \text{ OP } \pm T_{rl} \qquad (2)$$

The values T_{rj} and T_{rl} are variable or logical trips, and the minus(-) sign, if present, denotes the complement of the trip value. The operation OP is one of the logical operations AND, OR(inclusive or), or XOR(exclusive or).

Logical trips are evaluated following the evaluation of variable trip and are evaluated in numerical order. When T_{rj} (or T_{rl}) is a variable trip, new trip values are used; when T_{rj} is a logical trip used in logical trip expression i, new values are used when $j < i$ and old values are used when $j \geq i$.

2.2 Control System

The control system consists of several types of control components. Each component defines a control variable as a specific function of time-advanced quantities. The time-advanced quantities include hydrodynamic volume, pump, heat structure, reactor kinetics, trip quantities, and the control variables themselves (including the control variable being defined). This permits control variables to be developed from components that perform simple, basic operations.

In the following equations that define the control components and associated numerical techniques, Y_i is the control variable defined by the i-th control component, A_j, R, and S are real constants input by the user, I is an integer constant input by the user, V_j is a quantity advanced in time by SPACE and can include Y_i, t is time, and s is the Laplace transform variable. Superscripts involving the index n denote time levels. The name in parentheses to the right of the definition is used in input data to specify the component.

Arithmetic control components evaluate followings.

Components	Equations	Remarks
Addition-Subtraction	$Y = S(A_0+A_1V_1+A_2V_2+...)$	(SUM)
Multiplication	$Y_i = SV_1V_2...$	(MULT)
Division	$Y_i = \frac{S}{V_1}$ or $Y_i = \frac{SV_2}{V_1}$	(DIV)
Exponentiation	$Y_i = SV_1^I$ $Y_i = SV_1^R$	(POWERI) (POWERR)
Function	$Y_i = SF_1(V_1)$ or $SF_2(V_1)$ 1)	(FUNCTION)
Standard Function	$Y = S\,F(V_1, V_2, V_3, ...)$ 2)	(STDFNCTN)
Unit Trip	$Y_i = S \cdot U(\pm T_l)$	(TRIPUNIT)

1) where F_1 is a function defined by table lookup and interpolation. F_2 is a function of HYSTERISIS
2) where F is $|V_1|$, V_1^2, $\exp(V_1)$, $\log(V_1)$, $\sin(V_1)$, $\cos(V_1)$, $\tan(V_1)$, $\tan^{-1}(V_1)$, $\max(V_1, V_2, V_3\ldots)$, $\min(V_1, V_2, V_3\ldots)$.

Integration component evaluates

$$Y_i = S\int_0^t V_1 dt \qquad \text{(INTEGRAL)} \qquad (3)$$

Proportional-Integration component evaluates

$$Y_i = S\left(A_1 V_1 + A_2 \int_0^t V_1 dt\right) \text{(PROP-INT)} \quad (4)$$

or $Y_i(s) = S\left(A_1 + \frac{A_2}{s}\right) V_1(s)$

Lag control component evaluates

$$Y = \int_0^t \left(\frac{SV_1 - Y}{A_1}\right) dt \quad \text{(LAG)} \quad (5)$$

or $Y_i(s) = S\left(\frac{1}{1 + A_1 s}\right) V_1(s)$

Lead-Lag control component is defined in Laplace transform notation as

$$Y = \frac{A_1 SV_1}{A_2} + \int_0^t \left(\frac{SV_1 - Y}{A_2}\right) dt \ \text{(LEAD-LAG)} \ (6)$$

or $Y_i(s) = S\left(\frac{1 + A_1 s}{1 + A_2 s}\right) V_1(s)$

3. Test results

3.1 Test problem

As shown in Fig. 1, a simple pipe network with a pump and two valves is constructed. It consists of one pipe(7 cells, 1x1x1), one branch pipe (1 cell, 1x1x1), and two small pipes(7 cells, 0.5x1x1). Each pipe is connected to the branch pipe. The pump is located in a middle section of the main horizontal pipe, and two valves are placed at the end of each small pipe, respectively. The pump is controlled to regulate the main pipe flow rate using the proportional integral and lead-lag control units of SPACE. The valve on-off control test is also performed by using the hysteresis function control unit[2].

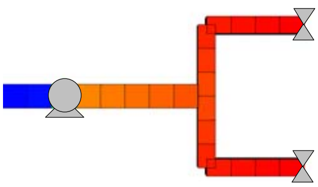

Fig. 1. Pipe network design to test trip and control models

3.2 Test results

As shown in Fig. 2, the pump flow rate is reasonably controlled to the set point, using PROP-INT control unit. In Fig.3, FUNCTION test result shows a good agreement on the function data given by general table. Fig. 4 shows that the hysteresis behavior can be well simulated by using HYSTERYSIS function control unit of SPACE.

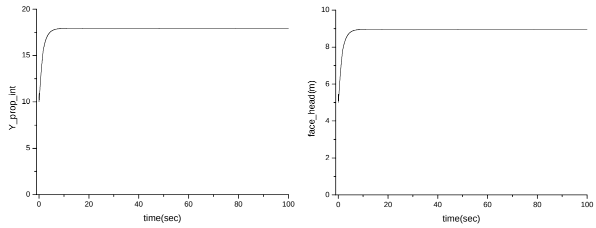

Fig. 2. Pump control test results using PROP-INT unit

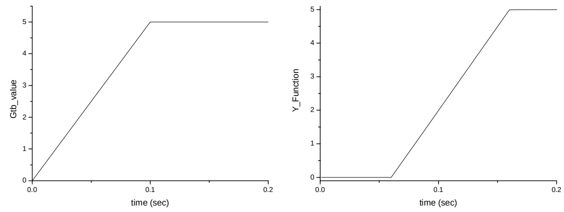

Fig. 3. Valve control test results using FUNCTION unit

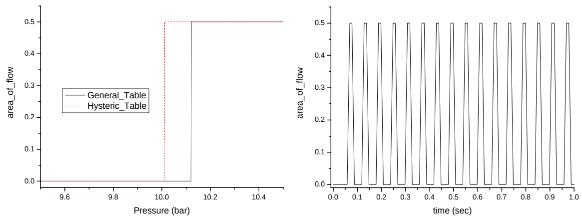

Fig. 4. Valve control test results using HYSTERYSIS function unit

4. Conclusions

Generalized trip and control units are developed and incorporated into the SPACE code. It can be seen from the test results that the trip and control system models work properly. The capability is primarily intended to simulate control systems typically used in nuclear reactor systems, but it can also model other phenomena described by algebraic and ordinary differential equations.

Acknowledgment

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REFERENCES

[1] S. Y Lee, Development of a Hydraulic Solver for the Safety Analysis Codes for Nuclear Power Plants (I), Korean Nuclear Society Spring Meeting, 2007.

[2] C. E Park, Extended COBRA-TF and its Application to Non-LOCA Analysis, ANS Winter Meeting, 2005.