TRACE Steady-State Modeling Options

Information Systems Laboratories, Inc.

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Objective

Provide information to help the user become aware of the different steady-state modeling options available in TRACE.

Outline

- Hydraulic-Path Steady-State Initialization Data
- Steady-State Controller Data
- Adjusted Additive Flow Loss Data

TRACE Steady-State Modeling Types

TRACE performs a transient calculation by successively evaluating the end-of-timestep solution for discrete timesteps and stepping forward in time.

This same procedure is followed when evaluating a steady-state calculation but with added internal-control features applied. Steady-state calculations generally are performed to provide the initial conditions for a transient calculation restart.

TRACE Steady-State Modeling Types

There are three types of steady-state calculations:

- generalized,
- constrained, and
- static check.

These different types are activated by specifying the correct input for STDYST in the main data cards (or in the Model Options/Steady-State Mode in SNAP).

STDYST calculation indicators include:

0 = no steady-state calculation (requires TRANSI input to be 1)

1 = generalized steady-state (GSS) calculation

2 = Constrained steady-state (CSS) calculation

3 = GSS calculation with hydraulic-path steady-state initialization (HPSSI)

4 = CSS calculation with HPSSI

5 = Static-check steady-state (SSS) calculation

TRACE Steady-State Modeling Types

A generalized steady-state (GSS) calculation asymptotically evaluates the time-independent steady-state solution of a modeled system where adjustable-hardware actions (like valve opening/closing, reactor scram, pump speed changes, etc) are held constant at their input-specified values.

A constrained steady-state (CSS) calculation is evaluated in the manner of a GSS calculation but with the addition of user-selected controllers that adjust specific component parameters (hardware actions) to achieve desired steady-state values for specific thermal-hydraulic parameters. These proportional-plus-integral (PI) controllers adjust somewhat uncertain hardware actions to achieve known or desired thermal-hydraulic conditions.

TRACE Steady-State Modeling Types

A static-check steady-state (SCSS) calculation checks for the presence of unknown or erroneous momentum or energy sources in the modeled system by setting the rotational speed of all pumps and all energy sources to zero. All coolant flow in the system should decelerate to zero because of wall-drag surface friction as the SCSS calculation is evaluated.

This option is a good check to see if there are any loop closure issues. Note that SNAP contains a “Check Model” routine that performs many checks of the input model including a check for loop closure.

Hydraulic-Path Steady-State Initialization Procedure

The initial solution estimate for a steady-state calculation is specified as part of the component data.

- It is easiest for the user to define this initial solution estimate at isobaric, isothermal, noflow, and no-power conditions.
- Doing so results in the steady-state calculation requiring more calculative effort to converge to the desired steady-state solution than if a better initial solution estimate were specified.

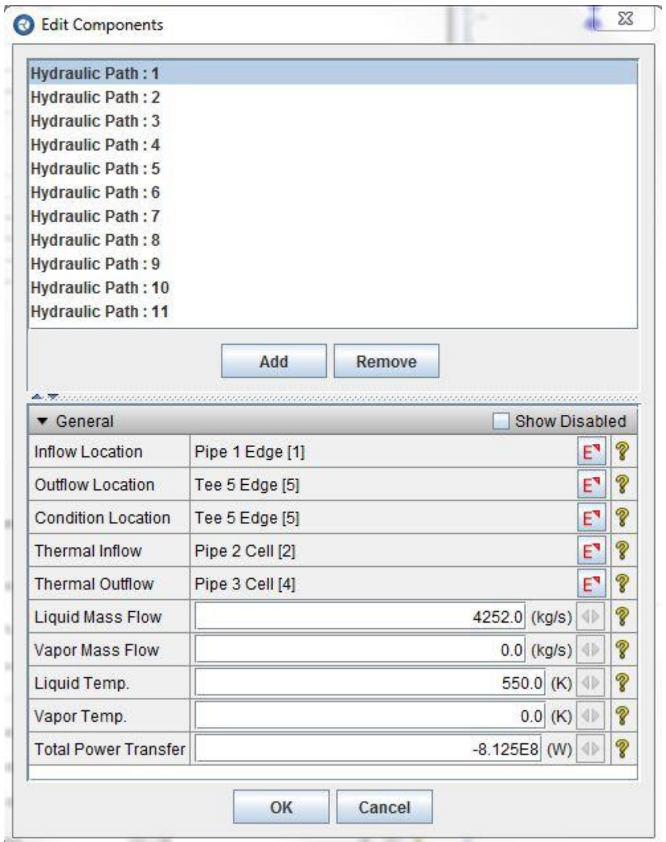
Hydraulic-Path Steady-State Initialization Procedure

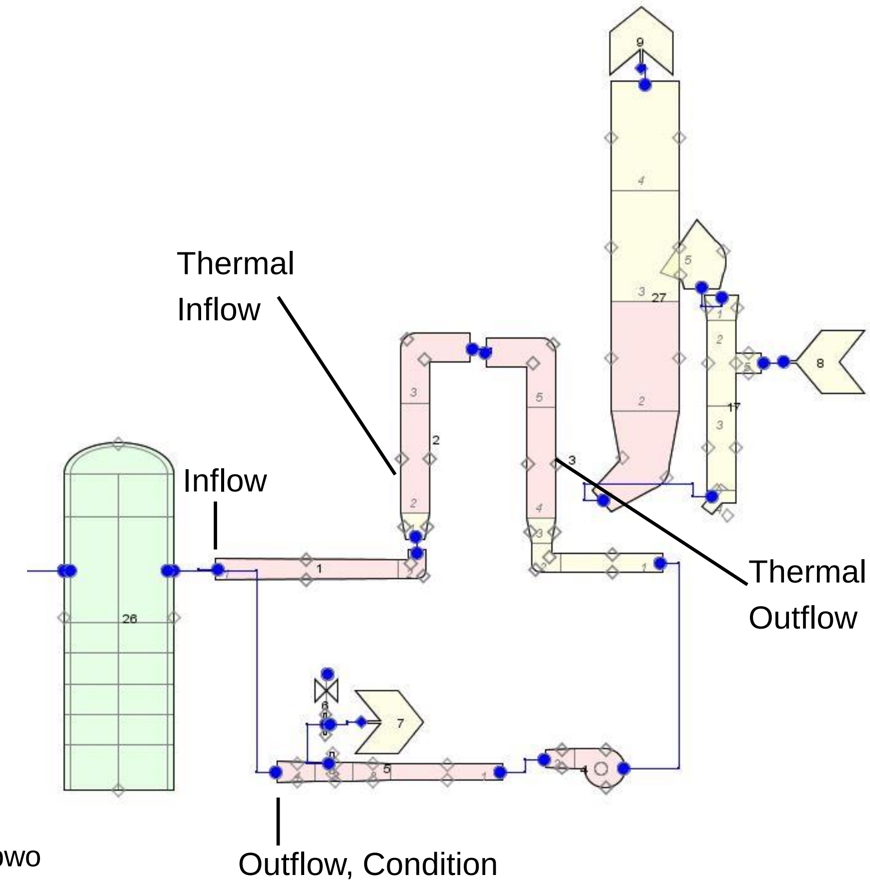
TRACE has the option of internally initializing better-estimate steady-state phasic temperature and velocity distributions with the hydraulic-path steady-state (HPSS) initialization procedure.

- Specify estimated steady-state temperature, coolant flow, and power source/sink for each hydraulic-path 1D flow channel.
- It is significantly easier to specify this thermal-hydraulic information for a dozen 1D flow channels than for a thousand mesh cells and interfaces in the system model.
- The calculative effort of the GSS or CSS calculation when applying this option generally is reduced by an approximate factor of two.

Hydraulic-Path Steady-State Initialization Procedure

Sample input for Hydraulic-Path Steady-State initialization process.





*	idcinf	idcouf	idcloc	idcpwi	idcpwo
	1001	5005	5005	2002	3004
*	pmvl	pmvv	ptl	ptv	ppower
	4252.0	0.0	550.0	0.0	-8.125E8

Adjusted Additive Flow Loss

- If a user desired steady-state pressure drop is known for a given cell edge in a TRACE input model and the additive flow loss is not known, then a Constrained Steady-State (CSS) Type 5 steady-state controller can be used to obtain the known pressure drop at steady-state conditions. This steady-state controller adjusts the additive flow loss to obtain the desired steady-state pressure drop during a TRACE steady-state calculation. The CSS Type 5 steady-state controller is only capable of controlling the additive flow loss to obtain a user desired pressure drop.

- A more general capability for adjusting additive flow loss factors is available with the Adjusted Additive Flow Loss Factor input.
  - Allows the user to define a control block output for the change in the additive flow loss factors.
  - The user has to define the control block that will be used as input to the adjusted additive flow loss model.
  - The adjustment can be based on any criteria as long as the control function is stable and converges in a reasonable time.
  - During the steady-state calculation, the adjusted additive flow loss factors are written to the restart dump file, so that the transient restart will use the adjusted additive flow loss factors consistent with the restart dump.
  - Example: gives the user the capability to adjust additive flow loss factors to obtain the flow split between core flow and core bypass flow or based on some other criteria.

Adjusted Additive Flow Loss

The input for the Adjusted Additive Flow Loss Factor data is simple:

- Fluid component number where the additive flow loss will be adjusted (COMPNUM).
- For 1D fluid components, cell edge number where the additive flow loss will be added, or for a VESSEL component (3D) the axial cell edge (ICELL).
- The radial direction index for the axial cell edge in a VESSEL component where the additive flow loss will be adjusted (JCELL). This input is ignored for a 1D component.
- The azimuthal direction index for the axial cell edge in a VESSEL component where the additive flow loss will be adjusted (KCELL). This input is ignored for a 1D component.
- Control block ID that will be used to adjust the additive flow loss at this fluid component cell edge (CBIDEN).

Adjusted Additive Flow Loss

Example Adjusted Additive Flow Loss Factor data input:

```
*
* Adjusted additive loss input.
* compNum      iCell      jCell      kCell      cbIden
        14          2          0          0         -2
*
```

In this example, the additive flow loss factor at cell face 2 of component 14 will be adjusted based on the output of control block 2. Control block 2 is a PI controller that will drive the differential pressure between cells 1 and 2 of component 14 to a setpoint of 2.5 bars.

Constrained Steady-State Controllers

Constrained Steady-State (CSS) Controllers are a user convenience available to drive a PWR or BWR plant simulation to user desired steady-state conditions.

- These controllers are internally programed PI controllers that adjust specific component features or internal parameters to achieve desired steady-state values for specific monitored parameters.
- CSS controllers are defined in the input when STDYST = 2 or 4.
- STDYST = 4 is the same as 2, but it also includes a hydraulic-path steady-state initialization.

Constrained Steady-State Controllers

There are five types of CSS controllers that can be used:

1. Type 1 Controller: Adjust PUMP rotational speed to match a user desired mass flow rate.
2. Type 2 Controller: Adjust VALVE flow-area fraction to match a desired upstream pressure or mass flow rate.
3. Type 3 Controller: Adjust FILL mass flow rate to match a desired mass flow rate at some other location in the input model.
4. Type 4 Controller: Adjust HTSTR heat transfer area or thermal conductivity or heat transfer coefficient multipliers or the hydraulic-channel pressure associated with the HTSTR surface to match a single-phase coolant temperature or void fraction.
5. Type 5 Controller: Adjust additive flow loss factors to match a user desired steady-state pressure drop.

Constrained Steady-State Controllers

The CSS controller input may use a composite number for specifying the component ID and the Cell, or Cell Face where the parameter action is adjusted.

The composite number for a 1D component is calculated as:

CompositeNum = CompNum * MAXNUM + i

Where:

- CompNum is the fluid component number
- i is the cell or cell face number
- MAXNUM is the maximum allowed component number in the input model that is defined by the input value of namelist variable CSSMAXNUMOPT (refer to Volume 1 of the Users input manual for details on MAXNUM and CSSMAXNUMOPT).

Constrained Steady-State Controllers

The composite number for a 3D component is calculated as:

CompositeNum = CompNum * MAXNUM + ij * 1000 + k

Where:

- ij is the horizontal cell index = (i -1) * NTSX + j,
- NTSX is the number of azimuthal cells in each ring of the VESSEL component,
- i is the radial ring index,
- j is the azimuthal sector index, and
- k is the axial level index

Constrained Steady-State Controllers

The CSS controller functionality is determined by three of the five CSS input variables:

1. NUMCSS: Component number where parameter action is adjusted. This parameter can be a component number for:
   - PUMP
   - VALVE
   - FILL
   - HTSTR
   - Composite cell-location number
2. NMPCSS: Monitored parameter number that depends upon which component type is referred by NUMCSS
   A. NUMCSS references a PUMP component
      - NMPCSS = -1 implies that mass flow rate is monitored
      - NMPCSS = 0 implies velocities are monitored
      - NMPCSS = composite number and NAPCSS = -1 then target mass flow rate is at the composite number location

Constrained Steady-State Controllers

2. NMPCSS: Monitored parameter number that depends upon which component type is referred by NUMCSS (continued)
   B. NUMCSS references a VALVE component
      - NMPCSS = -1 implies the VALVE flow area fraction is adjusted to match the initial condition pressure upstream of the VALVE face.
      - NMPCSS = 2 implies the VALVE flow area fraction is adjusted to match the initial condition mass flow rate entered at the valve face location.
      - NMPCSS = composite number then the valve area fraction is adjusted to match the mass flow rate at the composite cell-location
   C. NUMCSS references a FILL component
      - The FILL flow rate will be the same as the initial mass flow rate input at the monitored location
      - The monitored location is given by the composite cell-location input for NMPCSS
      - If NAPCSS = 1, then the adjusted flow rate is out of the FILL component
      - If NAPCSS = 2 then the adjusted flow rate is into the FILL component

Constrained Steady-State Controllers

2. NMPCSS: Monitored parameter number that depends upon which component type is referred by NUMCSS (continued)
   - D. NUMCSS references a HTSTR component
     - NMPCSS can be a composite cell-location where the coolant temperature or void fraction is monitored
     - NMPCSS can be a signal variable or a control block that will be use as the monitored parameter for adjusting the HTSTR surface area and or conductivity.
   - E. NUMCSS is greater than MAXNUM
     - NUMCSS is a composite cell-location number identifying the location where flow losses are adjusted to obtain a target differential pressure
     - NMPCSS is the composite cell-location number of the upstream pressure location
     - NAPCSS is the composite cell-location number of the downstream pressure location
     - The initial condition pressure inputs at NMPCSS and NAPCSS constitutes the target differential pressure
3. NAPCSS: Adjusted parameter number. NAPCSS can be used to determine the parameter that will be monitored

Summary Table of CSS Controllers

Controller Type	NUMCSS Type	Parameter to be Adjusted	NMPCSS	Desired Parameter	NAPCSS
1	PUMP	A	-1	Mass Flow	0
1	PUMP	A	0	Velocity	0
3	PUMP	A	Composite Number	Mass Flow	-1
2	VALVE	B	1	Upstream Pressure	0
2	VALVE	B	2	Mass Flow	0
3	VALVE	B	Composite Number	Mass Flow	0
3	FILL	C	Composite Number	Mass Flow Out	1
3	FILL	C	Composite Number	Mass Flow In	2
4	HTSTR	D	Composite Number, Signal Variable, Control Block	Coolant Temperature	5
4	HTSTR	E	Composite Number, Signal Variable, Control Block	Coolant Temperature	6
4	HTSTR	F	Composite Number, Signal Variable, Control Block	Coolant Temperature	7
4	HTSTR	G	Composite Number, Signal Variable, Control Block	Coolant Temperature	8
4	HTSTR	H	Composite Number, Signal Variable, Control Block	Coolant Temperature	9
4	HTSTR	I	Composite Number, Signal Variable, Control Block	Coolant Temperature	10
4	HTSTR	J	Composite Number, Signal Variable, Control Block	Coolant Temperature	11
4	HTSTR	K	Composite Number, Signal Variable, Control Block	Coolant Temperature	12
4	HTSTR	L	Composite Number, Signal Variable, Control Block	Coolant Temperature	13
4	HTSTR	M	Composite Number, Signal Variable, Control Block	Coolant Temperature	14
5	Cell Edge	N	Composite number pointing to upstream pressure	Differential Pressure	Composite number pointing to downstream pressure

A – pump speed
B – valve area
C – mass flow
D – inner surface BREAK pressure
E – outer surface BREAK pressure

F – inner surface heat transfer area
G – outer surface heat transfer area
H – inner and outer surface heat transfer area
I – inner surface node conductivity
J – inner surface node conductivity

K – inner and outer surface node conductivity
L – all radial nodes conductivity
M – inner and outer surface area and all radial nodes conductivity
N – cell edge additive flow los factor

CSS Controller Cautions and Guidance

1. The other inputs for the CSS controllers include minimum and maximum adjustment values.
   - When HTSTR CSS controllers are being used, they should not significantly change the heat structure surface areas and/or the thermal conductivity.
     - Minimum and maximum adjustment values are used to support variations in manufacturing pipe diameter tolerances and crud buildup during operation. Should be no more than -10% and +2%.
     - If adjustments exceed these tolerances, then BREAK pressure adjustments should be considered

2. When CSS controllers are used to adjust a valve flow area to obtain a secondary side pressure (turbine control valve) the user must be aware of the resulting valve open area fraction.
   - Generally turbine control valve area versus power level are typically provided.
   - If the calculated valve area is less than or greater than the operating valve area then that suggests that:
     - The flow losses are off in the steam line,
     - The BREAK back pressure is off
     - Or both
3. When using CSS controllers to adjust the additive flow loss at a cell edge, the user should use ball park estimates for the form loss and fluid velocities at the adjusted cell edge.
4. After steady conditions are achieved using CSS controllers, the user should verify the adjusted parameters give the same results if they are incorporated into the model and the GSS control is used.

CSS Example

*** loop 1 pumps 4 and 5 controller adjusts impeller rotational speed**

*** to match initial flow rate in PUMP components.**

*	numcss	amncss	amxcss	nmpcss	napcss
	4	200.0	500.0	-1	0
	5	200.0	500.0	-1	0

*** loop 1 steam-flow control valve type-2 controller adjusts upsteam pressure**

*	numcss	amncss	amxcss	nmpcss	napcss
	23	0.0	1.0	1	0

CSS controller inputs 1 and 2:

- NUMCSS = 4 and 5 identify loop reactor coolant pumps.
- NMPCSS = -1 specifies the target value is mass flow rate.
- A target mass flow rate of 245 kg/s is specified as an initial condition in PUMP 4 and PUMP 5 at cell face 2, the location for the pump impeller action.

CSS controller input 3:

- NUMCSS = 23 identifies steam line turbine control valve.
- NMPCSS = 1 specifies the valve flow area is adjusted to obtain a target upstream pressure.
- The target pressure, 5.75 MPa, is input as an initial condition at cell 3 (upstream of the valve face) in VALVE 23.

Questions?

Any questions on Steady-State modeling options before moving on?