PWR Model Setup – Exercise 2

Objectives

- Become familiar with the PUMP component configuration.
- Learn to use control blocks to control the PUMP speed.
- Gain some basic familiarity with the process used to calculate homologous pump curves which are used by TRACE to calculate the pump pressure head.
- Learn to use the input switch control block.

Overview of Steps

1. Configure pump 115

A) Add rated conditions

B) Add a pump speed controller

C) Run steady state case and examine pump response

2. Calculate, add, and test single phase head curves

A) Calculate and add the homologous pump curves

B) Complete control systems to calculate curve variables

C) Run a steady state case and examine pump response

Step 1 Configure pump 115

The pump component models the interaction between a centrifugal pump and the fluid passing through the pump. It calculates the pressure differential caused by the pump as a function of the pump rotational speed and the fluid boundary conditions for the pump. Configuration options are included to model single phase and two phase flow and to calculate the coast down response of the pump.

The pump component includes parameters used in configuring a pipe component. The pump specific parameters can, in general, be grouped into the following categories:

1. Parameters used to control the pump rotational speed or flow rate (i.e., trips, tables, and control parameters)
2. Parameters that impact the pump pressure differential (i.e., single phase head curves, fully degraded (two-phase) head curves, head degradation multiplier, rated head-flow-speed, and specified flow rate or rotational speed)
3. Parameters that impact the pump coast down rate (i.e., impeller moment of inertia, single phase torque curves, full degraded (two-phase) torque curves, torque degradation multiplier, and the frictional torque coefficients).

The exercise will provide some experience with adding a control system to adjust the rotational speed (Item 1) and calculating and configuring head curves (Item 2). The process for calculating torque curves (Item 3) is very similar to the process for calculating head curves, so some notes on the process will be given, but the exercise will not include calculation of torque curves. The frictional torque coefficients (Item 3) are not covered in this exercise.

Step A) Add rated conditions

One of the basic configuration items needed for each pump is the rated conditions. Rated conditions for a pump are typically made available by the pump manufacturer. How these are given varies. Below are a set of typical rated conditions that might be provided for a pump by the manufacturer. The rated flow is given in units accepted by TRACE. However, the rated head and speed need to be converted to units of m^2/s^2 and rad/s respectively. In this step, we will convert the units and then add the rated values to the pump 115.

Table 1: Pump Rated Values

	Symbol	Value	Units
Rated Flow	Qr	5.5835	m^3/s
Rated Head	Hr1	79.537	m
Rated Speed	Ωr1	1180.3	RPM

1. Go to the folder Day2\Afternoon\Plant_Exercise_Part_2\ and double click on PWR-SS-Ex2.med to open the TRACE plant model.
2. Locate the pump for loop 1 (component 115). If you would like to use the find dialog to do this, press ctrl-F. Select pump component 115.
3. In the Properties Window, expand the ▸ Rated Values section by clicking on it. The properties Rated Head, Rated Volumetric Flow, and Rated Speed are not set. Since the Rated Flow value in Table 1 above is already in the units expected by TRACE, set the Rated Volumetric Flow to the value in Table 1.
4. An excel workbook is available to help convert rated head and rated speed to the units in Table 1 to the units used in TRACE. Open the file, LoftPumpRatedValues.xlsx in the same folder as the med file and follow the instructions provided. After calculating Rated Head and Rated Speed, bring up the SNAP Model Editor again, make sure pump 115 is still selected, and using the calculated results set these values in the ▸ Rated Values section in the Properties Window.
5. TRACE includes four built-in homologous pump curves. In the Properties Window, go to the ▾ General section and find the Pump Curve Option. Note that this is currently set to [2] Built-in LOFT Curves.

Step B) Add a pump speed controller

This step provides some experience in configuring a pump and to use a control system to set the pump speed. A simple control system will be constructed.

1. We will use a function block to specify the pump speed as a function of time. On the Toolbar, click the icon and select Control Systems ►Control Blocks. Click on a blank spot somewhere below pump 115. Select a Function block and click OK. One quick way to find this is sorting by the Type column.

2. In the Properties Window, set the following:
   - Control Block Name = Pump Speed
   - Control Block Number = -50

3. The function block allows you to define a function of 1, 2, or 3 variables. In this case we only need one variable: time. To set time as the function input, expand Input Connections in the Properties Window. Click on the Source table value for input 1 which should contain a <none> value. Click the select button that appears. In the selection dialog, find and click on Problem Time 1 (you can sort by the Component column) and select OK. Click OK in the Define Input Sources dialog.

4. To define the function:

   a. Expand the Function Table property. In the Editing Function Table dialog, click the Add button thee times to add three entries in the table.

   b. We will specify a function that causes the rotation to decrease from 123.6 rad/s to 45 rad/s over the first 30 seconds, then increase from 45 rad/s to 180 rad/s from 30 to 100 seconds. Add the following values to the table and click OK.

Time s	No Unit -
0.0	123.6
30.0	45.0
100.0	180.0

5. Select pump 115 if it is not selected, and in the Properties Window, under the ▼ General section, set the Pump Type to [1] Table Controlled Impeller Rotation.

6. In the Properties Window, click for the Speed/Torque Var. property. This control block sets the pump speed. Select the function control block -50 that was defined above and click OK.

The Speed Trip property indicates a trip that is used to enable and disable the pump controller. If the trip is not set, the pump controller is active by default. If you want to ensure that a pump controller is active, set the Speed Trip to None.

7. To make sure the pump controller will be active, delete the Speed Trip controller by clicking the select button, and in the Select from Trips dialog click the None button.

TRACE includes a simple steady state controller called a constrained steady state controller for controlling pumps and other components to match certain common steady state conditions. More information will be given about configuring constrained steady state controllers on Day 4. If the pump is controlled via a constrained steady state controller, the pump controller implemented in this exercise will not function properly. In this case, you need to remove the constrained steady state controller or disable constrained steady state mode.

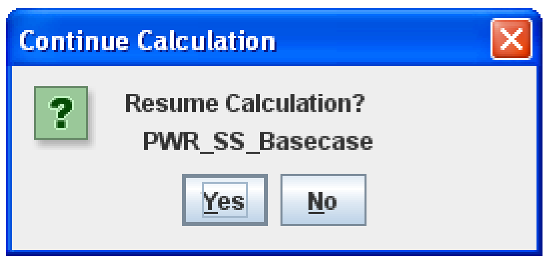
8. In the Navigator Window, select the Model Options item. In the Properties View, find the Steady State Mode parameter and note that the mode is set to [2] CSS Calculation

(Constrained Steady State Calculation). To see which components are being controlled via a constrained steady state controller, find the Constrained Steady State property and click the expand icon. Click CSS Controller: 1 in the list and note that this a controller for Pump 115. To keep this from conflicting with the controller that we added to the pump, click the Remove button then click OK.

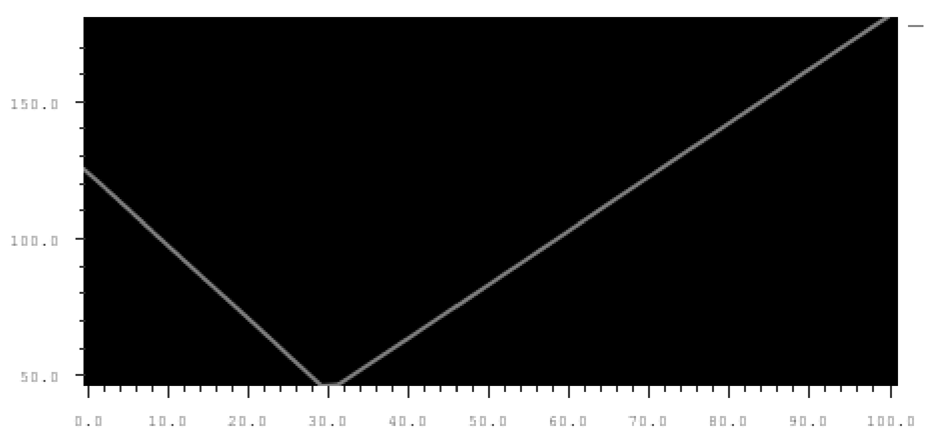
Step C) Run steady state case and examine pump response

1. To run the 100 second transient simulation and verify that it is working, select Tools►Submit Job from the SNAP Menu. Select OK in the Submit Job Stream dialog. If a Submit Stream dialog appears, click OK again.

2. The SNAP Job Stream window will open. The animation model should open shortly thereafter with the following dialog. Click Yes.



3. In the animation model that opens, click on the Pump Response tab in the View Window. The view contains a plot of the pump speed, volumetric flow, and pump head. The pump speed should look like the response shown below.



✓ The pump controller has been added that controls the rotational speed of the pump. Pump controllers can be used to reach steady state conditions before a transient event is started or to simulate coast down response if the coast down rate is known. However, it is usually preferable to include torque data and let TRACE calculate coast down rates.

Step 2. Calculate, add, and test single phase head curves

The pressure head produced by a pump can be expressed as a function of the volumetric flow through the pump and the impeller rotational speed (a two dimensional chart). Many pumps exhibit a symmetry in the pressure head vs. flow and impeller speed relationship that can be exploited to reduce this relationship down to a one dimensional line that captures the pressure head produced by the pump at all operating conditions.

Using the symmetry to reduce the pump data down to a single curve results in a set of curves called the **homologous curves**. The word homologous means "having the same structure" and just indicates that the curve takes advantage of symmetry to capture a wide range of pump conditions in a more compact form.

TRACE uses homologous pump curves for head, torque, and two phase degraded flow. The exercise guides you through the process of reducing pump head information to homologous curve data. The pump data used is consistent with the LOFT pump curves included in TRACE.

Step A) Calculate and add the homologous pump curves

1. The folder \Day2\Afternoon\Plant_Exercise_Part_2 contains an excel file named LoftPumpCurves.xlsx. Open this workbook and follow the instructions for calculating the homologous head curves for the LOFT pump. After completing the exercise, leave excel open so that the pump data can be added to the model.

2. Go to the SNAP Model Editor application and select pump 115 if it is not selected.

3. In the Properties Window, under the ▼ General section, set the Degradation Option to [0] Single Phase Curves. Set the Pump Curve Option to [0] User Specified Curves.

> When two phase mixture enters a pump, the pump performance degrades significantly. TRACE allows you to model the degraded performance via degradation curves and a degradation multiplier to interpolate between the single phase curves and degradation curves as a function of void fraction. Unfortunately the degraded performance information is not provided by the manufacturer in most cases and requires additional experimental data or the values must be assumed.

> A common misconception when first encountering the degradation curve is that this is used to specify the pump curves for STEAM. This is incorrect. The single phase curves apply to BOTH pure liquid and pure steam. The degradation curves are used to model degraded pump performance of two-phased flow.

4. Copy the head curve regions into the pump by doing the following:

a. In the Properties Window, expand the ▸ Curves section and click for the Single-phase Head property. A dialog will appear where you set the homologous curve data. At the top of the dialog is a field that shows Region 1. If you click on this field, the options will appear, which include regions 1 through 4. We need to add the data for each of these regions.

b. Go to the LoftPumpCurves.xlsx excel workbook and select the Region 1 table (illustrated below) by left clicking on cell with 0 in it, and while holding the mouse button down, drag the cursor to the bottom of the Region 1 table (the green cell seen below with 1.00 in it), then release the mouse button. Copy the table by either pressing ctrl-C or by right clicking inside the selected region and choosing copy from the pop up menu.

Region 1	
q/ω	h/ω^2
0	1.40
0.4000024	1.30
0.8200007	1.09
1	1.00

c. Go back to the SNAP Model Editor application. The Homologous Curves dialog should still be open. With the field at the top set to Region 1, right click in the table (i.e. the empty white region in the dialog) and select paste. The Region 1 values from excel should be copied into the cell.

d. Set the field at the top of the Homologous Curves dialog to Region 2, then follow the process indicated above to copy the values for region 2 from excel and paste them into the table. Click OK.

Manufacturer data is typically limited to the expected operational region and excludes conditions such as flow going backwards through the pump. TRACE does not require you to provide complete pump curve information. However, if the pump reaches a state that is not defined by the pump curves, the simulation will fail with the following message:

```
#################
## Fatal Error ##
#################

*pumpd*cannot locate head curve
```

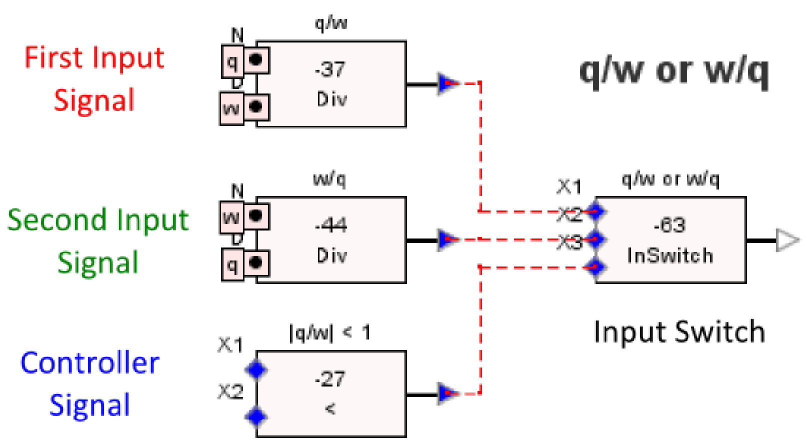
5. The single phase torque curves need to be included in the model as well. These are included in the excel workbook in the section below the head curve tables. In the Properties Window, click the E for Single-phase Torque. Copy the region 1 through 4 torque curves from excel into the Homologous Curves dialog. Remember to change the Region field at the top of the Homologous Curves dialog as you paste each new region table from excel.

It is common for power vs. flow rate to be included with manufacturer pump data rather than torque. Fortunately, it is simple to convert between power and torque for a motor. Unit conversions may be needed to make the equation consistent, but the relationship is:

Power = Torque x Rotational Speed

Step B) Complete control systems to calculate curve variables

The **Input Switch** control block accepts three control block connections, two input signals and one controller signal. An example switch is shown below. Based on the value of the controller signal, the Input Switch will either output the value of the first signal or the second signal. When the controller signal is 1, the value of the first signal is output from the switch. When the controller signal is set to 0, the value of the second signal is output from the switch.



> **Input Switch** control blocks allow you to switch from one set of logic to another set of logic to control a component. One common use for this is to switch between a controller used to reach a steady state and a controller that models operational behavior that would be active during a transient event. In addition, the behavior of a component may change based on events that occur in the transient, such as reactor trip, and the Input Switch can be used to change the control logic before and after the event. Some components allow you to specify trips cause the control mechanism to change, so Input Switches are not always required.

In this step we will configure an Input Switch to get experience with how this control block works. A description of how the Input Switch will be used is given below.

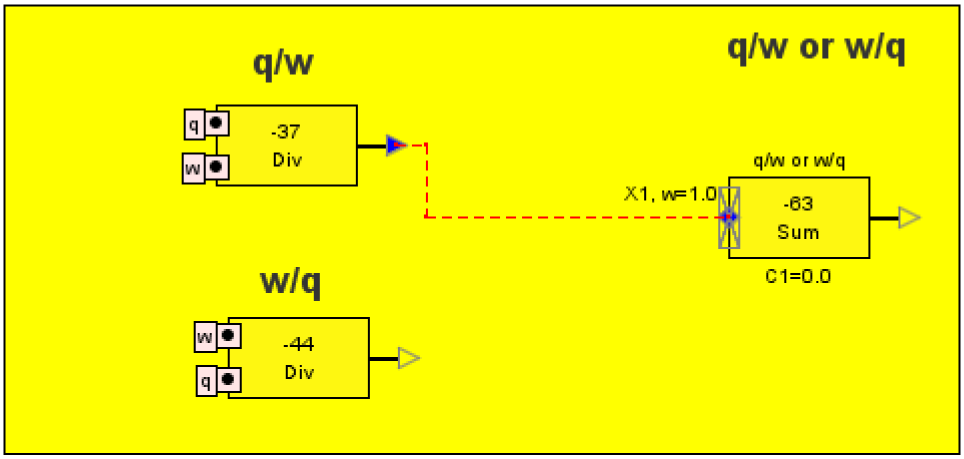
To verify that the homologous curves were added correctly, a plot of the correct homologous curve is included in the animation file. The homologous curve parameters for region 1 differ from the curve parameters for region 2. The parameters for region 1 and region 2 are shown in the table below:

Region	Condition	Curve Parameters	
		Parameter 1	Parameter 2
Region 1	$\lvert q/\omega \rvert <= 1$	q/ω	h/ω^2
Region 2	$\lvert q/\omega \rvert >= 1$	ω/q	h/q^2

Control blocks are included in the model which calculate for pump 115 the parameters for region 1 (i.e., q/ω and h/ω^2) as well as the parameters for region 2 (i.e., ω/q and h/ω^2). To verify that the pump 115 homologous curves were added to the model correctly, we will plot the point where pump 115 is on the homologous curve against the actual curve. If the curves have been added correctly and the Input Switch is set up correctly, the point representing the state of pump 115 will remain on the homologous curve.

The Input Switch is needed to switch between the set of parameters used when the pump state changes between region 1 and region 2. So, before examining the response of pump 115, we will configure the Input Switch which allows us to transition between the parameters used for region 1 and the parameters used for region 2.

> To configure the input switches to select the correct homologous curve parameters for pump 115 do the following:

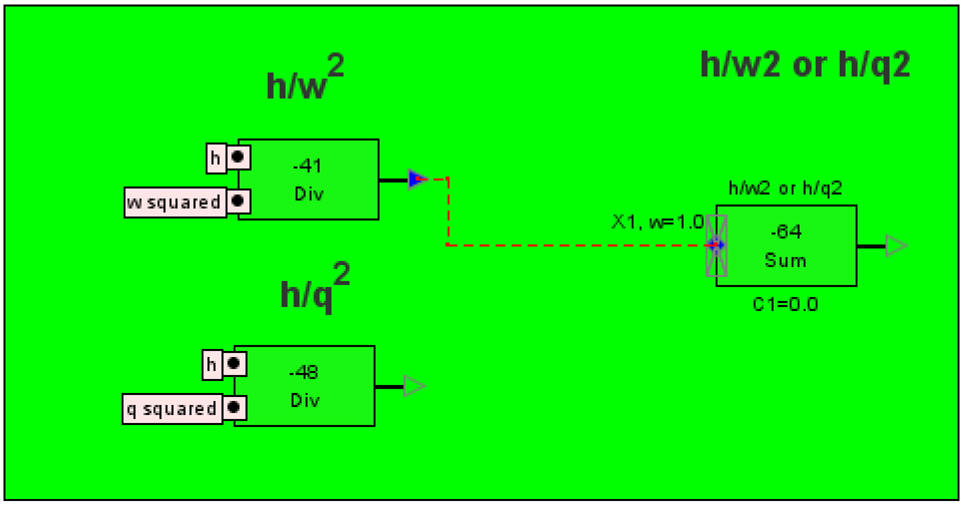


1. In the View Window, select the Homologous Curve Params tab. In the Model Editor, locate the yellow box titled q/w or w/q as shown above. The box contains contains blocks -37 and -44 which calculate q/w and w/q. It also contains Sum block -63 which is included as a place holder and will be converted to an Input Switch block. The q/w and w/q blocks are the two input signals for the Input Switch. The controller signal is block -27 which tests whether block q/w is in the range -1 to 1. If q/w is in the range -1 to 1 block -27 will return 1. Otherwise it will return 0. Locate block -27 in the blue box.

2. To convert Sum block -63 (in the yellow box) to an Input Switch, click on block -63 and in the Properties Window click on [S] for the Type property. From the Select Control Type dialog, choose the Input Switch control block type (you can sort by the Type column to find this).

3. Choose the connection tool [icon] from the Toolbar and connect from w/q block -44 (in the yellow box) to the middle connection point of Input Switch block -63 (also in the yellow box). The input signals q/w and w/q are now connected to the Input Switch, but we still need to connect the controller.

4. To connect the controller, find block -27 in the blue box, and connect from this block to the bottom connection point on Input Switch block -63. The Input Switch should now correctly choose between parameters q/w and w/q as pump 115 changes between region 1 and region 2.



5. Now we need to do the same process for the parameters h/w^2 and h/q^2. In the Model Editor, locate the green box titled h/w^2 or h/q^2 as shown above. This contains blocks -41 and -48 which calculate h/w^2 and h/q^2 respectively. It also contains Sum block -64 which is also a place holder. The blocks h/w^2 and h/q^2 are the two input blocks for this Input Switch, and again block -27 (in the blue box) is the controller.

6. To convert Sum block -64 (in the green box) to an Input Switch, click on block -64 and in the Properties Window click on for the Type property. From the Select Control Type dialog, choose the Input Switch control block type (you can sort by the Type column to find this).

7. Choose the connection tool from the Toolbar and connect from h/q^2 block -48 (in the green box) to the middle connection point of Input Switch block -64 (also in the green box). The input signals h/w^2 and h/q^2 are now connected to the Input Switch, and we just need to connect the controller.

8. Find block -27 (in the blue box) and connect from this block to the bottom connection point on Input Switch block -64. The Input Switch should now correctly choose between parameters h/w^2 and h/q^2 as pump 115 changes between region 1 and region 2.

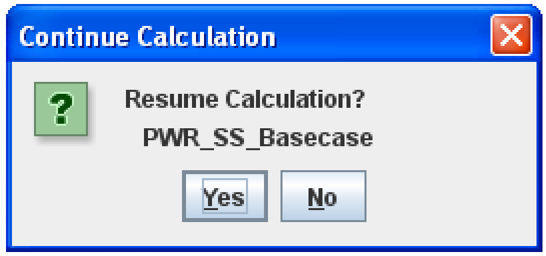
✓ Control block -63 is now configured to switch between q/w and w/q and control block -64 will switch between h/w2 and h/q2 to stay on the TRACE homologous head curve.

Step C) Run a steady state case and examine pump response

We will now run a simulation to verify that the homologous curves were added to the model correctly. Control blocks -63 and -64 are the homologous curve variables for pump 115 this point will be plotted along with the homologous curves for Region 1 and 2, in the animation file. The pump state is shown as a red circle and the homologous curves are represented as a blue line. To run the simulation, do the following:

1. To run the 100 second transient simulation, select Tools►Submit Job from the SNAP Menu. Select OK in the Submit Job Stream dialog. If a Submit Stream dialog appears, click OK again.

2. The SNAP Job Stream window will open. The animation model should open shortly thereafter with the following dialog. Click Yes.



3. In the animation model that opens, click on the HOMOLOGOUS CURVE tab in the View Window. Initially the red dot will NOT be on the blue line because the plot values for the pump have not been initialized in the animation file have not been initialized. As the simulation proceeds to the first plot point, The red dot should jump to the blue line and remain on the blue line.

FINAL REMARKS

- As mentioned in the exercise, TRACE includes constrained steady state controllers for pumps. These can be used to reach a target steady state mass flow or velocity through the pump. These are worth keeping in mind since they are simple to add and configure. We will see these again in the day 4 exercises.
- The pump includes two types of torque input: the homologous torque curves and the frictional torque coefficients. The homologous curves model torque due to interaction between the impeller and the fluid. Frictional torque coefficients model torque caused by friction and by bearing and windage. The frictional torque includes polynomial terms through cubic order