TYPE 695: VARIABLE SPEED PUMP, CONTROL SIGNAL INPUT, POWER CALCULATED FROM HEAD AND DESIRED FLOW RATE

General Description

Type695 models a pump that sets its outlet mass flow rate equal to a user specified maximum mass flow rate multiplied by a control signal that can vary between a value of 0 and 1. By insuring that the control signal only ever has a value of 0 or 1 (never anything in between) Type695 can equally well be used to model a constant speed pump. Like most pumps and fans in TRNSYS, Type695 ignores the inlet mass flow rate of liquid and sets the downstream flow. The pump's power draw is calculated based upon a user specified polynomial. Pump starting and stopping characteristics are not modeled.

Nomenclature

$\dot{m}$	[kg/hr]	Mass flow rate of liquid passing though the pump.
$\dot{m}_{rated}$	[kg/hr]	Maximum mass flow rate of liquid that can pass though the pump.
Cp	[kJ/kg.K]	The specific heat of the liquid being pumped.
ΔP	[kPa]	Pressure rise of liquid as it passes through the pump.
γ	[0..1]	Pump control signal (0:OFF, 1:ON)
ρ	[kg/m^3]	The density of the liquid being pumped.
η_{motor}	[0..1]	Efficiency of the pump motor
$\eta_{overall}$	[0..1]	Overall pump efficiency (motor efficiency * pumping efficiency)
$\eta_{pumping}$	[0..1]	Efficiency of pumping the fluid
$a_0, a_1, a_2 \ldots$	[-]	Polynomial coefficients in the pump power curve
η_{motor}	[-]	Efficiency of the pump motor
$f_{motorloss}$	[0..1]	Fraction of pump motor inefficiencies that contribute to a temperature rise in the liquid stream passing through the pump. The remainder of these inefficiencies contribute to an ambient temperature rise.
$\dot{P}$	[kJ/hr]	Power drawn by the pump.
$\dot{P}_{shaft}$	[kJ/hr]	Shaft power required by the pumping process (does not include motor inefficiency)
$\dot{Q}_{liquid}$	[kJ/hr]	Energy transferred from the pump motor to the liquid stream passing through the pump.
$\dot{Q}_{ambient}$	[kJ/hr]	Energy transferred from the pump motor to the ambient air surrounding the pump.
$T_{liquid,out}$	[ºC]	The temperature of liquid exiting the pump
$T_{liquid,in}$	[ºC]	The temperature of liquid entering the pump

Detailed Description

As inputs, Type695 takes liquid pressure rise, inlet temperature, inlet flow rate, and a control signal having a value between 0 and 1. If the pump is determined to be OFF (it's control signal is set to 0), the outlet mass flow rate, power drawn, energy transferred to ambient and energy transferred to the liquid stream are all set to zero. The temperature of liquid exiting the pump under the OFF condition is set to the temperature of liquid at the pump inlet. If, however, the pump is determined to be ON (control signal

greater than 0) then the mass flow rate of liquid exiting the pump is set to the current value of the inlet mass flow rate specified in the model's input list multiplied by the control signal as shown in equation 695.1

$$\dot{m} = \gamma \, \dot{m}_{rated} \qquad \text{(Eq. 695.1)}$$

The efficiency at which the pump is operating is given by equation 695.2.

$$\eta_{overall} = a_0 + a_1\left(\frac{\dot{m}}{\dot{m}_{rated}}\right) + a_2\left(\frac{\dot{m}}{\dot{m}_{rated}}\right)^2 + a_3\left(\frac{\dot{m}}{\dot{m}_{rated}}\right)^3 + \ldots \qquad \text{(Eq. 695.2)}$$

The same equation could equally well be written as shown in equation 695.2a since the ratio of current mass flow rate to rated mass flow rate comes directly from the pump control signal.

$$\eta_{overall} = a_0 + a_1 \, \gamma + a_2 \, \gamma^2 + a_3 \, \gamma^3 + \ldots \qquad \text{(Eq. 695.2a)}$$

To model a constant speed pump using Type695, the user should insure that the control signal set as an input to the model always has the same value. A variable speed pump is modeled simply by allowing the control signal to vary between 0 and 1.

Based on the calculated overall pump efficiency and the user supplied motor efficiency, the efficiency of the pumping process can be calculated from the relation

$$\eta_{overall} = \eta_{pumping} \, \eta_{motor} \qquad \text{(Eq. 695.3)}$$

The power required at the shaft is given by equation 695.4.

$$\dot{P}_{shaft} = \frac{\dot{m} \, \Delta P}{\rho \, \eta_{pumping}} \qquad \text{(Eq. 695.4)}$$

Energy transferred from the pump motor to the liquid stream is calculated as shown in equation 695.5

$$\dot{Q}_{fluid} = \dot{P}_{shaft}\left(1 - \eta_{pumping}\right) + \left(\dot{P} - \dot{P}_{shaft}\right) f_{motorloss} \qquad \text{(Eq. 695.5)}$$

In which $\eta_{pumping}$ is the pumping efficiency and $f_{motorloss}$ is a value between 0 and 1 that determines whether the pump motor inefficiencies cause a temperature rise in the liquid stream that passes through the pump or whether they cause a temperature rise in the ambient air surrounding the pump. Through use of the $f_{motorloss}$ fraction, the user can in effect specify whether the pump has an inline motor, in which case all waste heat would impact the liquid stream temperature and $f_{motorloss}$ would have a value of 1, or whether the pump motor is housed outside of the liquid stream such that it's waste heat impacts the ambient and $f_{motorloss}$ would have a value of 0.

The energy transferred from the pump motor to the ambient is given by equation 695.6.

$$\dot{Q}_{ambient} = \left(\dot{P} - \dot{P}_{shaft}\right)\left(1 - f_{motorloss}\right) \quad \text{(Eq. 695.6)}$$

The temperature of liquid exiting the pump can now be calculated as shown in equation 695.7.

$$T_{liquid,out} = T_{liquid,in} + \frac{\dot{Q}_{liquid}}{\dot{m}\ Cp} \quad \text{(Eq. 695.7)}$$

Type695 does not model pump starting and stopping characteristics; as soon as the control signal indicates that the pump should be ON or that the pump should change speeds due to a change in control signal value, the outlet flow of liquid jumps to match the inlet flow rate. The time constants with which pumps react to input changes are much shorter than the typical time steps used in hydronic simulations.