TYPE 748: VARIABLE SPEED PUMP, DESIRED MASS FLOW RATE INPUT, MATCH SYSTEM CURVE AND HEAD CURVE

General Description

Type748 models a pump whose outlet mass flow rate is based upon a user supplied ON/OFF signal, a user specified desired mass flow rate and the intersection point between a user specified system head curve (polynomial) and a series of user specified pump head curve for various pump speeds (external data file). Like most pumps and fans in TRNSYS, Type748 takes the inlet mass flow rate of fluid as an input but does not necessarily pass the value through to its output. Type748 sets the downstream flow based solely upon the pump / system curve intersection point.

Nomenclature

H	[m]	Head
h	[0..1]	Normalized pump head
$\dot{P}$	[kJ/hr]	Power drawn by the pump.
$\dot{P}_{shaft}$	[kJ/hr]	Shaft power required by the pumping process (does not include motor inefficiency)
$a_0, a_1, a_2 \ldots$	[-]	Polynomial coefficients in the system head curve
γ	[0..1]	Normalized mass flow rate (desired flow rate / rated flow rate)
Cp	[kJ/kg.K]	Specific heat of pump fluid
η_{motor}	[-]	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
$\dot{Q}_{fluid}$	[kJ/hr]	Energy transferred from the pump motor to the fluid stream passing through the pump.
$f_{motorloss}$	[0..1]	Fraction of pump motor inefficiencies that contribute to a temperature rise in the fluid stream passing through the pump. The remainder of these inefficiencies contribute to an ambient temperature rise.
$\dot{Q}_{ambient}$	[kJ/hr]	Energy transferred from the pump motor to the ambient air surrounding the pump.
$T_{fluid,out}$	[kJ/kg]	Temperature of fluid exiting the pump
$T_{fluid,in}$	[kJ/kg]	Temperature of fluid entering the pump
Δp	[Pa]	Pump pressure rise
ρ_{fluid}	[kg/m^3]	Density of fluid flowing through the pump
$\dot{m}$	[kg/hr]	Mass flow rate of fluid flowing through the pump.

Detailed Description

Type748 operates in such a way that when ON (control signal input set greater than 0.5), the volumetric and mass flow of fluid through the pump is determined by the intersection point of the system curve and the pump head curve that is closest to a user specified “desired mass flow rate”. The curves and their intersection points are shown graphically in Figure 1. Because the pump curves are specified in an

external data file and are read by the TRNSYS Data Reading subroutine, Type748 is able to interpolate between curves provided for specific pump speeds and match the user specified desired pump flow rate.

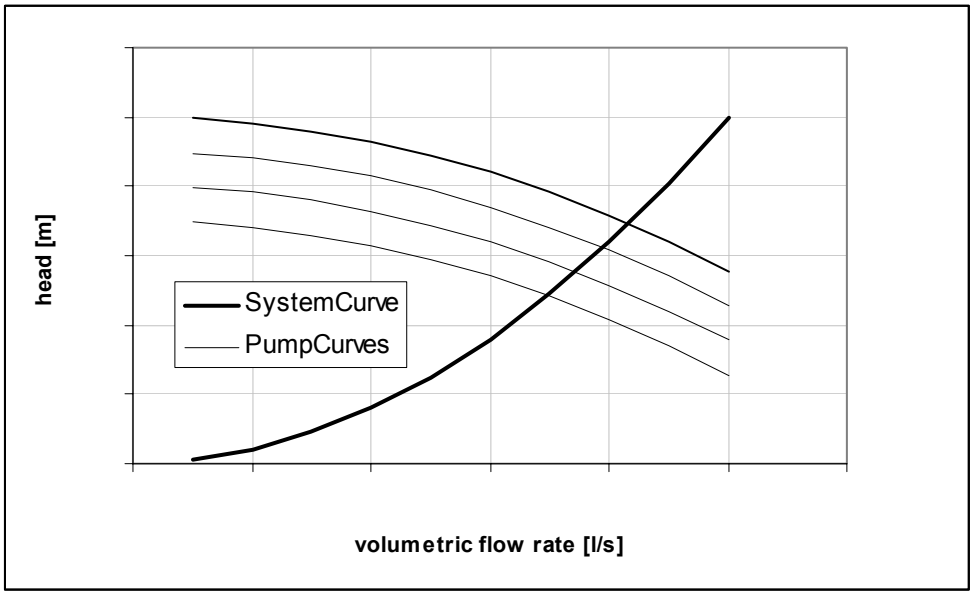


Figure 1: System Curve and Pump Curves for Various Pump Speeds

The fluid loop (system) curve is specified by the user as a polynomial. Equation 748.1 shows the form of the system curve equation in which γ is the desired flow rate divided by the pump's rated flow rate. As such, γ is a normalized mass flow rate for which a value of 0 corresponds to no flow, and a value of 1 corresponds to the pump's rated flow. "h" is the normalized system head with a value of 0 indicating zero head and a value of 1 indicating rated head.

$$h = a_0 + a_1\gamma + a_2\gamma^2 + a_3\gamma^3 + \ldots \qquad \text{(Eq. 748.1)}$$

If the pump is determined to be OFF (control signal input set to less than 0.5) then the temperature of fluid at the pump outlet is set to the temperature of fluid at the pump inlet. Pump flow rate, power, efficiency, head, energy transferred to the fluid and energy transferred to the ambient are all set to zero.

If, however, the pump is ON, then Type748 performs an iterative search to determine the operating point. Type748 first queries the data reading routine to find pump head at the desired volumetric flow rate and zero speed; this is obviously an unrealistic first guess but it provides a base point from which the pump speed will be increased by steps until the pump head that matches the system head is found. One important point about the TRNSYS data reading subroutine bears mention. While the data reading routine interpolates between data points, it does not extrapolate beyond the data range. When a value outside of the data file range (in this case a volumetric flow or a fractional pump speed greater than the maximum or less than the minimum in the data set) either the minimum or maximum values will be returned and the data reading routine will print a warning to the list file. If the calculated system head is equal to the returned pump head, the intersection point has been found and the pump speed has been correctly guessed. If the returned pump head is less than the calculated system head less than the returned pump head then the pump speed is too small. A new (higher) speed is guessed and the process recommences. If the returned pump head is less than the system head, then the pump speed is too high, the speed step size is decreased and a new guess is made. If ever the condition of fractional pump speed

= 1 is reached without having reached an intersection point, Type748 generates an error and warns the user that it was unable to find the pump operating point. The simulation is stopped in this case.

Once the intersection point has been found, the pump volumetric flow rate is known. The pump pressure rise (equal to the system pressure drop) is calculated according to equation 748.2

$$\Delta p = \frac{9.81\, H\ \rho_{fluid}}{1000} \qquad \text{(Eq. 748.2)}$$

Where H is the matched system and pump head expressed in meters.

The user supplied values of motor efficiency and the overall efficiency returned from the data reading routine are used to calculate the efficiency of the pumping process as follows:

$$\eta_{pumping} = \frac{\eta_{overall}}{\eta_{motor}} \qquad \text{(Eq. 748.3)}$$

The pump shaft power (ignoring motor inefficiencies) is calculated using equation 748.4

$$\dot{P}_{shaft} = \frac{\dot{m}\ \Delta p}{\rho_{fluid}\ \eta_{pumping}} \qquad \text{(Eq. 748.4)}$$

The overall power drawn by the pump is then calculated as

$$\dot{P} = \frac{\dot{P}_{shaft}}{\eta_{motor}} \qquad \text{(Eq. 748.5)}$$

The energy transferred from the pump motor to the fluid is given by equation 748.6.

$$\dot{Q}_{fluid} = \dot{P}_{shaft}\left(1-\eta_{pumping}\right)+\left(\dot{P}-\dot{P}_{shaft}\right)f_{motorloss} \qquad \text{(Eq. 748.6)}$$

In equation 747.6, $\eta_{pumping}$ is the pumping process efficiency (returned from the data file) and $f_{motorloss}$ is a value between 0 and 1 that determines whether the pump motor inefficiencies cause a temperature rise in the fluid 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 fluid stream temperature and $f_{motorloss}$ would have a value of 1, or whether the pump motor is housed outside of the fluid stream such that it's waste heat impacts the ambient and $f_{motorloss}$ would have a value of 0.

The energy transferred to the ambient is given by equation 748.7

$$\dot{Q}_{ambient} = \left(\dot{P}-\dot{P}_{shaft}\right)\left(1-f_{motorloss}\right) \qquad \text{(Eq. 748.7)}$$

And the outlet temperature is given by equation 748.8

$$T_{fluid,out} = T_{fluid,in} + \frac{\dot{Q}_{fluid}}{\dot{m}\ Cp} \qquad \text{(Eq. 748.8)}$$

The external data file that defines the pump head curve must follow the standard syntax for a two dimensional data file. That is to say that values of pumpable head and overall pump efficiency must be supplied in columns for each of a series of volumetric flow rates and for a series of fractional pump speeds. Each of these series must be specified on its own line at the top of the file. An example file containing data for eleven values of volumetric flow rate and three values of fractional pump speed is shown below. Please note that the file is merely provided as a syntactical reference and does not contain realistic values.

Example Pump Data File

```
0.0  1.0  2.0  3.0  4.0  5.0  6.0  7.0  8.0  9.0  10.0    ! Volumetric flow rate [l/s]
0.0  0.5  1.0                                              ! Fractional pump speed [0..1]
6.100    1.0                  ! Pumpable head and Overall pump efficiency at 0.0 l/s and 0.0 speed
6.000    0.9                  ! Pumpable head and Overall pump efficiency at 1.0 l/s and 0.0 speed
5.870    0.8                  ! Pumpable head and Overall pump efficiency at 2.0 l/s and 0.0 speed
5.600    0.7                  ! Pumpable head and Overall pump efficiency at 3.0 l/s and 0.0 speed
5.260    0.6                  ! Pumpable head and Overall pump efficiency at 4.0 l/s and 0.0 speed
4.950    0.5                  ! Pumpable head and Overall pump efficiency at 5.0 l/s and 0.0 speed
4.490    0.4                  ! Pumpable head and Overall pump efficiency at 6.0 l/s and 0.0 speed
4.070    0.3                  ! Pumpable head and Overall pump efficiency at 7.0 l/s and 0.0 speed
3.600    0.2                  ! Pumpable head and Overall pump efficiency at 8.0 l/s and 0.0 speed
3.000    0.1                  ! Pumpable head and Overall pump efficiency at 9.0 l/s and 0.0 speed
1.960    0.0                  ! Pumpable head and Overall pump efficiency at 10.0 l/s and 0.0 speed
6.100    1.0                  ! Pumpable head and Overall pump efficiency at 0.0 l/s and 0.5 speed
6.000    0.9                  ! Pumpable head and Overall pump efficiency at 1.0 l/s and 0.5 speed
5.870    0.8                  ! Pumpable head and Overall pump efficiency at 2.0 l/s and 0.5 speed
5.600    0.7                  ! Pumpable head and Overall pump efficiency at 3.0 l/s and 0.5 speed
5.260    0.6                  ! Pumpable head and Overall pump efficiency at 4.0 l/s and 0.5 speed
4.950    0.5                  ! Pumpable head and Overall pump efficiency at 5.0 l/s and 0.5 speed
4.490    0.4                  ! Pumpable head and Overall pump efficiency at 6.0 l/s and 0.5 speed
4.070    0.3                  ! Pumpable head and Overall pump efficiency at 7.0 l/s and 0.5 speed
3.600    0.2                  ! Pumpable head and Overall pump efficiency at 8.0 l/s and 0.5 speed
3.000    0.1                  ! Pumpable head and Overall pump efficiency at 9.0 l/s and 0.5 speed
1.960    0.0                  ! Pumpable head and Overall pump efficiency at 10.0 l/s and 0.5 speed
6.100    1.0                  ! Pumpable head and Overall pump efficiency at 0.0 l/s and 1.0 speed
6.000    0.9                  ! Pumpable head and Overall pump efficiency at 1.0 l/s and 1.0 speed
5.870    0.8                  ! Pumpable head and Overall pump efficiency at 2.0 l/s and 1.0 speed
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1.960    0.0                  ! Pumpable head and Overall pump efficiency at 10.0 l/s and 1.0 speed
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