TYPE 749: VARIABLE SPEED PUMP, POWER INPUT, MATCH SYSTEM CURVE AND HEAD CURVE

General Description

Type749 models a pump whose outlet mass flow rate is based upon a user specified amount of available power 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, Type749 takes the inlet mass flow rate of fluid as an input but does not necessarily pass the value through to its output. Type749 sets the downstream flow based solely upon the pump / system curve intersection point.

Nomenclature

H	[m]	Pump or system head
$H_{\max}$	[m]	Maximum pumpable head
h	[0..1]	Normalized pump head
$\dot{P}$	[kJ/hr]	Power drawn by the pump.
$\dot{P}_{\max}$	[kJ/hr]	Power drawn by the pump at rated conditions.
$\dot{P}_{shaft}$	[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}	[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
$\dot{Q}_{fluid}$	[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.
$\dot{m}_{\max}$	[kg/hr]	Mass flow rate of fluid flowing through the pump at rated conditions.

Detailed Description

Type749 operates in such a way that when ON (power is available), 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 whose pressure drop and resultant power draw corresponds most closely with the currently available amount of power. 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, Type749 is able to interpolate between curves provided for specific pump speeds and match the user specified desired pump flow rate. 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 either the minimum or maximum values will be returned and the data reading routine will print a warning to the list file.

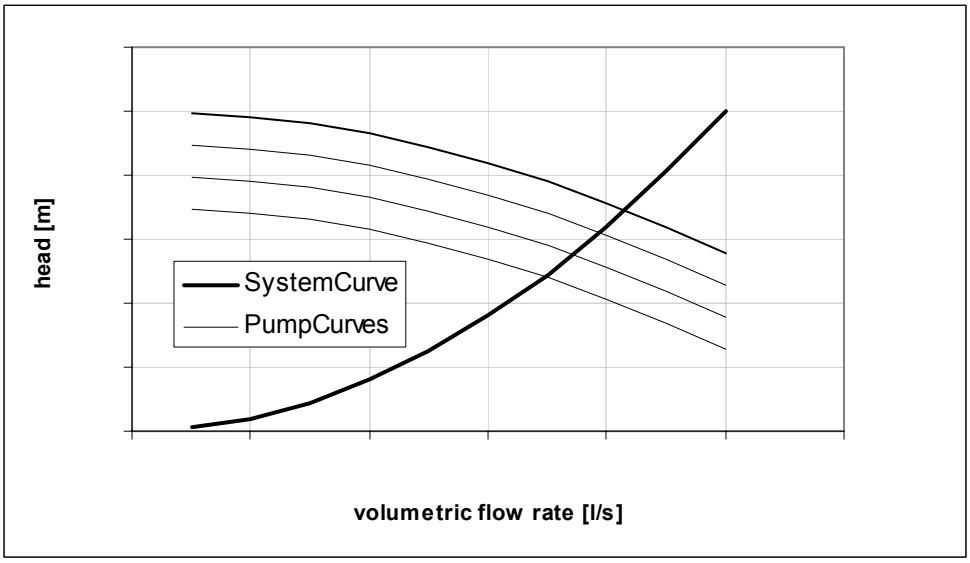


Figure 1: System Curve and Pump Curves for Various Pump Speeds

The fluid loop (system) curve is specified by the user as a polynomial. Equation 749.1 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 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.

$$h = a_0 + a_1\gamma + a_2\gamma^2 + a_3\gamma^3 + \ldots \qquad \text{(Eq. 749.1)}$$

If the pump is determined to be OFF (power available input set to zero) 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 Type749 performs a series of two iterative searches to determine the operating point. In the first iterative search, Type749 queries the Data Reading routine to find the pumpable head that matches the calculated system head at the pump's maximum rotational speed. This intersection point is farthest to the right and farthest to the top in Figure 1, corresponding to the maximum pumpable volumetric flow rate/head combination. From this intersection point it is possible to calculate the maximum shaft power that can be drawn by the pump / system combination that is described by the equation 749.1 polynomial and the external data file. If more power than this maximum is available, the pump is known to be operating at its rated condition. Maximum power is calculated using equations 749.2 and 749.3 in which Δp is the pressure rise across the pump (or the pressure drop

of the system) at rated conditions. The overall pump efficiency is returned by the TRNSYS Data Reading routine.

$$\Delta p = \frac{9.81\, H_{\max}\ \rho_{fluid}}{1000} \qquad \text{(Eq. 749.2)}$$

$$\dot{P}_{\max} = \frac{\dot{m}_{\max}\ \Delta p}{\rho_{fluid}\ \eta_{overall}} \qquad \text{(Eq. 749.3)}$$

If the result of equations 749.2 and 749.3 is a maximum power greater than the available power, a second iterative search must be initiated in order to find the actual operating point. Before the intersection search is initiated, Type749 checks for the two cases shown in Figure 2, both of which would result in a failed iterative search. The red portions of the lines in Figure 2 are included to show that the Data Reading routine *does not* extrapolate beyond the specified range but instead holds the maximum or minimum value.

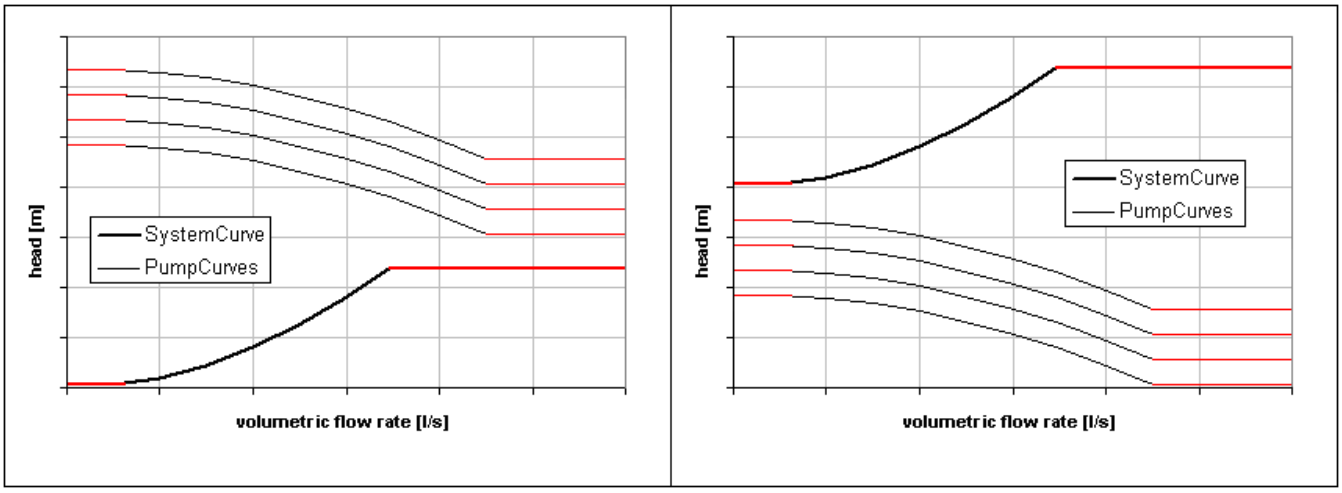


Figure 2: Insolvable (Non Intersecting) Pump / System Curves

Having insured that a solution is possible, values of normalized flow are guessed, an intersection point is found and equations 749.2 and 749.3 are repeatedly solved until a power matching the available power is found. The range of volumetric flows is broken into a number of steps (the default is 1000), which is set in the Fortran code of the component. Users wishing to increase the speed of calculations may recompile the code with fewer steps. Users wishing to increase the precision of calculations may recompile with more steps. If, during the iterative process the of normalized volumetric flow = 1 is reached without having reached an intersection point, Type749 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 is found, the overall pump power draw and pressure rise are known. The shaft power (excluding motor inefficiencies from the overall power) is calculated as

$$\dot{P}_{shaft} = \eta_{motor}\ \dot{P} \qquad \text{(Eq. 749.4)}$$

The pumping efficiency can be calculated as

$$\eta_{pumping} = \frac{\eta_{overall}}{\eta_{motor}} \quad \text{(Eq. 747.3)}$$

Where $\eta_{overall}$ is returned from the TRNSYS data reading routine and η_{motor} is a user supplied input to the model.

The energy transferred from the pump motor to the fluid can then be calculated from equation 749.4.

$$\dot{Q}_{fluid} = \dot{P}_{shaft}\left(1-\eta_{pumping}\right)+\left(\dot{P}-\dot{P}_{shaft}\right)f_{motorloss} \quad \text{(Eq. 749.5)}$$

In equation 749.5, $\eta_{pumping}$ is the pumping process efficiency 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 749.6

$$\dot{Q}_{ambient} = \left(\dot{P}-\dot{P}_{shaft}\right)\left(1-f_{motorloss}\right) \quad \text{(Eq. 749.6)}$$

And the outlet temperature is given by equation 749.7

$$T_{fluid,out} = T_{fluid,in} + \frac{\dot{Q}_{fluid}}{\dot{m}\ Cp} \quad \text{(Eq. 749.7)}$$

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 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
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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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