TYPE 750: VARIABLE SPEED PUMP, FRACTION OF RATED SPEED INPUT, MATCH SYSTEM CURVE AND HEAD CURVE

General Description

Type750 models a variable speed pump whose flow rate is calculated based on the intersection of the pump curve and the system curve. The user must specify coefficients of the system curve polynomial (head pressure versus flow rate) and must provide an external data file containing the pump curve (head versus flow rate) at several values of the rotational speed. Type750 will attempt to find a flow rate that provides the same system head and pump head given the provided fraction of rated rotational speed. Like most pumps and fans in TRNSYS, Type750 takes the inlet mass flow rate of fluid as an input but does not necessarily pass the value through to its output. Type750 sets the downstream flow based solely upon the pump / system curve intersection point.

Nomenclature

$H_{intersection}$	[m]	Pump or system head at the pump curve / system curve intersection
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
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

Type750 operates in such a way that when ON (fractional rotational speed is greater than zero), the volumetric and mass flow of fluid through the pump is determined by the intersection point of the system curve and the pump head. 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 subroutine, Type750 is able to interpolate between curves provided for specific pump speeds and match the user specified fractional rotational pump speed. 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.

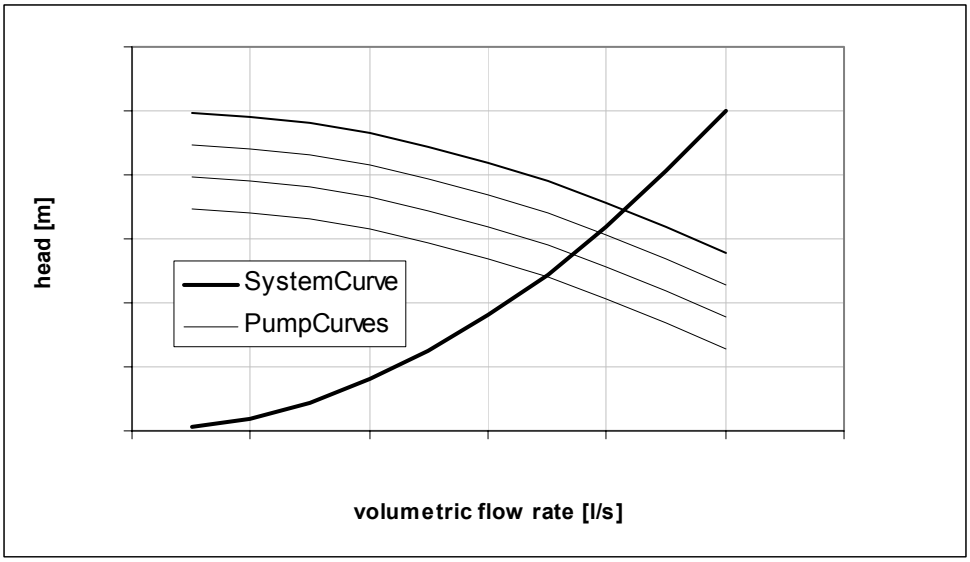


Figure 1: System Curve and Pump Curves for Various Pump Speeds

During preprocessing, Type750 checks to insure that the no flow system head specified as a parameter falls between the minimum and maximum pump heads provided in the external data file.

While pump curves are provided in an external file, the fluid loop (system) curve is specified by the user as a polynomial. Equation 750.1 shows the form of the system curve equation in which γ is a normalized flow rate for which a value of 0 corresponds to no flow, and a value of 1 corresponds to the system'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.

$$h = a_0 + a_1\gamma + a_2\gamma^2 + a_3\gamma^3 + ... \qquad \text{(Eq. 750.1)}$$

If the pump is determined to be OFF (fraction of rated rotational speed 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 (fraction of rated rotational speed greater than zero), then Type750 chooses a value of non dimensional flow (γ) and a value of volumetric flow. It evaluates equation 750.1 with the value of non dimensional flow and queries the TRNSYS Data Reading routine with the value of volumetric flow and the user specified fraction of rated pump rotational speed. In return, the Data Reading routine provides corresponding values of pump head and efficiency. The system head and pump head are compared; if they are equal, then the intersection point of the two curves has been found. If the system head is less than the pump head, the value of non dimensional flow (γ) and volumetric flow are increased by a predefined step size, equation 750.1 is reevaluated and the Data Reading routine is

queried once again. If the system head is greater than the pump head, then the iterative search has stepped over the intersection point. The values of non dimensional flow (γ) and volumetric flow are backed up to their previous guess values, the step size is decreased by an order of magnitude and new values are guessed. Through this method the intersection of the pump curve that corresponds to the user specified fraction of rated rotational speed and the system curve is found. Iteration stops when the intersection point is found. However, two other conditions can cause the iteration to stop. The first is that the initial guess values of both non dimensional and volumetric flow are set to zero. Progressive guess values increase towards the pump's maximum volumetric and non dimensional flow. If ever the guessed non dimensional flow rate goes above 1, then the system / pump curve system has been examined and no intersection point was found; iteration is correspondingly stopped, outputs are set to zero and an error message is generated. The other condition that stops iteration does not result in an error. If during the iterative process, the step size becomes too small iteration stops and values as close to the iteration point as possible are reported.

Once the pump / system head at the intersection has been found, the pressure rise across the pump (or the pressure drop of the fluid loop) can be determined using equation 750.2 and the power drawn by the pump can be determined from 750.3

$$\Delta p = \frac{9.81\, H_{intersection}\ \rho_{fluid}}{1000} \qquad \text{(Eq. 750.2)}$$

$$\dot{P} = \frac{\dot{m}\ \Delta p}{\rho_{fluid}\ \eta_{overall}} \qquad \text{(Eq. 750.3)}$$

The shaft power (excluding the effects of motor inefficiencies is

$$\dot{P}_{shaft} = \eta_{motor}\ \dot{P} \qquad \text{(Eq. 750.4)}$$

The pumping efficiency can be calculated as

$$\eta_{pumping} = \frac{\eta_{overall}}{\eta_{motor}} \qquad \text{(Eq. 750.5)}$$

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 750.6.

$$\dot{Q}_{fluid} = \dot{P}_{shaft}\left(1-\eta_{pumping}\right)+\left(\dot{P}-\dot{P}_{shaft}\right)f_{motorloss} \qquad \text{(Eq. 750.6)}$$

In equation 750.6, $\eta_{pumping}$ 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 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 $f_{\text{motorloss}}$ would have a value of 0.

The energy transferred to the ambient is given by equation 750.7

$$\dot{Q}_{ambient} = \left(\dot{P} - \dot{P}_{shaft}\right)\left(1 - f_{motorloss}\right) \qquad \text{(Eq. 750.7)}$$

And the outlet temperature is given by equation 750.8

$$T_{fluid,out} = T_{fluid,in} + \frac{\dot{Q}_{fluid}}{\dot{m}\ Cp} \qquad \text{(Eq. 750.8)}$$

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 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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3.000    0.1                  ! Pumpable head and Overall pump efficiency at 9.0 l/s and 1.0 speed
1.960    0.0                  ! Pumpable head and Overall pump efficiency at 10.0 l/s and 1.0 speed
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