TYPE 747: CONSTANT SPEED PUMP, MASS FLOW RATE CALCULATED FROM MATCHING SYSTEM CURVE AND HEAD CURVE

General Description

Type747 models a pump whose outlet mass flow rate is based upon a user supplied ON/OFF signal and the intersection point between a user specified system head curve (polynomial) and a user specified pump head curve (external data file). Like most pumps and fans in TRNSYS, Type747 takes the inlet mass flow rate of fluid as an input but does not necessarily pass the value through to its output. Type747 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 volumetric 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.

Detailed Description

Type747 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. The curve and their intersection point is shown graphically in Figure 1.

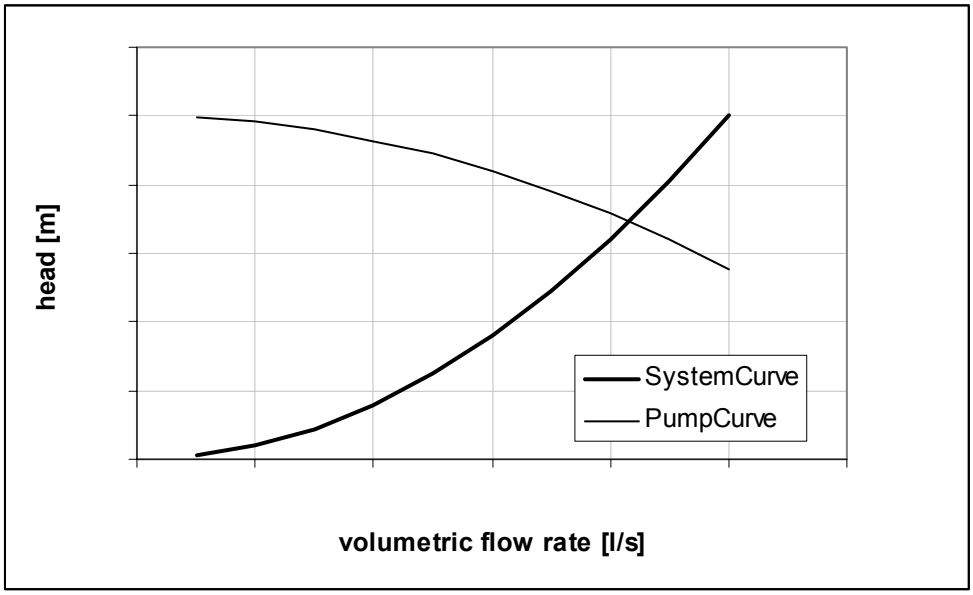


Figure 1: Example Pump and System Curves

The fluid loop (system) curve is specified by the user as a polynomial while the pump curve is specified in an external data file following the standard TRNSYS data file format. Equation 747.1 shows the form of the system curve equation in which γ is a normalized volumetric flow variable 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.

$$h = a_0 + a_1\gamma + a_2\gamma^2 + a_3\gamma^3 + \ldots \qquad \text{(Eq. 747.1)}$$

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 Type747 performs an iterative search to determine the operating point. An initial volumetric flow rate guess is made and the corresponding value of gamma is calculated. The normalized fluid loop head at the guessed value of gamma is calculated, again using equation 747.1. The TRNSYS Data Reading subroutine is then called with the guessed value of volumetric flow (non normalized). The data reading routine queries a user provided external data file, returning values of overall pump efficiency and head for the guessed flow rate. One important point about the TRNSYS Data Reading subroutine is that while it 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 greater than the maximum or less than the minimum volumetric flow in the data set) either the minimum or maximum value 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 flow rate has been correctly guessed. If the calculated system head is less than the returned pump head then the flow rate is too small. A new (higher) flow rate is guessed and the process recommences. In the third case, the calculated system head is greater than the returned pump head, meaning that the guessed volumetric flow rate is too large. A smaller flow rate is guessed and new values of pump and system head are calculated. The normal initial guess of normalized volumetric flow rate is 0 and subsequent guesses are made with increasing values of gamma. If ever the condition of gamma = 1 is

reached without having reached an intersection point, Type747 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 747.2

$$\Delta p = \frac{9.81\, H\ \rho_{fluid}}{1000} \qquad \text{(Eq. 747.2)}$$

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:

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

The pump shaft power is then calculated using equation 747.4

$$\dot{P}_{shaft} = \frac{\dot{m}\ \Delta p}{\rho_{fluid}\ \eta_{pumping}} \qquad \text{(Eq. 747.4)}$$

The total power drawn by the pump includes the effects of both pumping inefficiency and motor inefficiency. It is calculated using equation 747.5

$$\dot{P} = \frac{\dot{P}_{shaft}}{\eta_{motor}} \qquad \text{(Eq. 747.5)}$$

The energy transferred from the pump motor to the fluid is given by equation 747.6.

$$\dot{Q}_{fluid} = \dot{P}_{shaft}\left(1-\eta_{pumping}\right)+\left(\dot{P}-\dot{P}_{shaft}\right)f_{motorloss} \qquad \text{(Eq. 747.6)}$$

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 747.7

$$\dot{Q}_{ambient} = \left(\dot{P}-\dot{P}_{shaft}\right)\left(1-f_{motorloss}\right) \qquad \text{(Eq. 747.7)}$$

And the outlet temperature is given by equation 747.8

$$T_{fluid,out} = T_{fluid,in} + \frac{\dot{Q}_{fluid}}{\dot{m}\ Cp} \qquad \text{(Eq. 747.8)}$$

The external data file that defines the pump head curve must follow the standard syntax for a one 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, which are specified on a single line at the top of the file. An example file containing data for eleven volumetric flow rates 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]
6.100    1.0                                 ! Pumpable head and Overall pump efficiency at 0.0 l/s
6.000    0.9                                 ! Pumpable head and Overall pump efficiency at 1.0 l/s
5.870    0.8                                 ! Pumpable head and Overall pump efficiency at 2.0 l/s
5.600    0.7                                 ! Pumpable head and Overall pump efficiency at 3.0 l/s
5.260    0.6                                 ! Pumpable head and Overall pump efficiency at 4.0 l/s
4.950    0.5                                 ! Pumpable head and Overall pump efficiency at 5.0 l/s
4.490    0.4                                 ! Pumpable head and Overall pump efficiency at 6.0 l/s
4.070    0.3                                 ! Pumpable head and Overall pump efficiency at 7.0 l/s
3.600    0.2                                 ! Pumpable head and Overall pump efficiency at 8.0 l/s
3.000    0.1                                 ! Pumpable head and Overall pump efficiency at 9.0 l/s
1.960    0.0                                 ! Pumpable head and Overall pump efficiency at 10.0 l/s
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