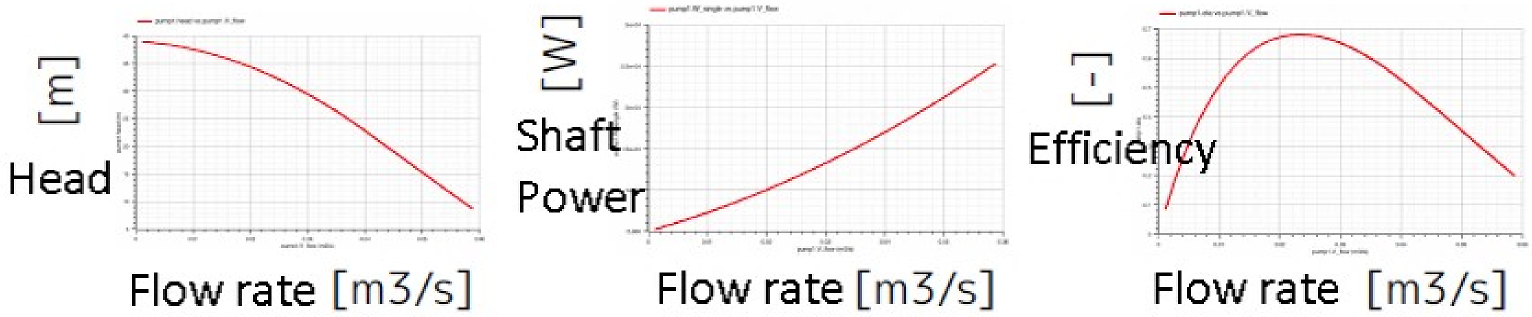
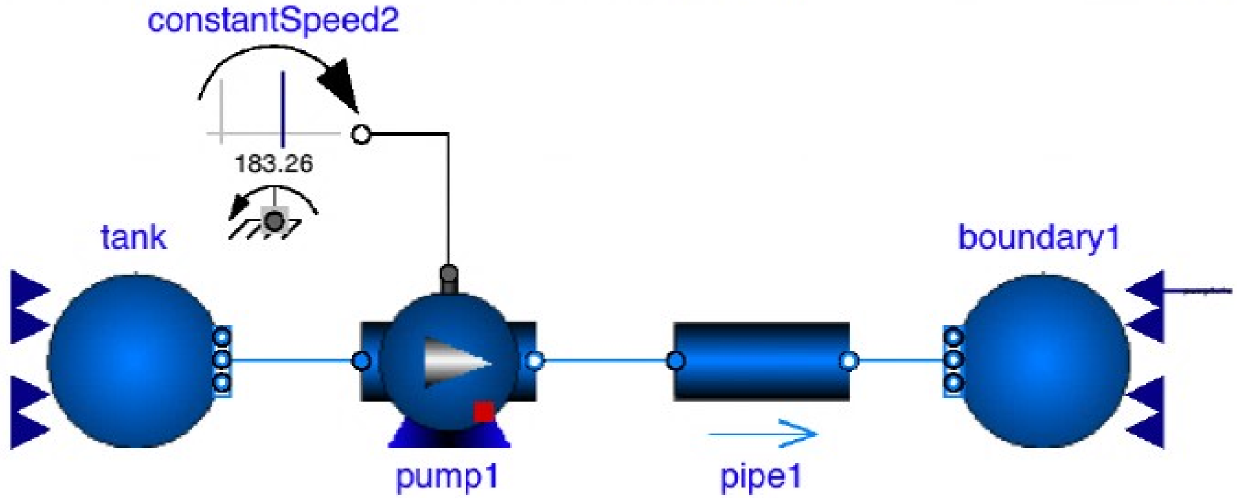
Modelica.Fluid.Machines

About the centrifugal pump model





2019/05/25 11th Modellca Library Study Meeting

finback

This document introduces a study of the centrifugal pump model included in Modelica.Fluid.Machines of the Modelica Standard Library, based on information obtained from source code and other sources. This pump model models the operation of the pump using head characteristics and power characteristics or efficiency characteristics obtained from pump manufacturers' data sheets and experiments.

Contents

- Basic knowledge of centrifugal pump
- Inheritance relationship of centrifugal pump model
- **PartialPump** (Base model of centrifugal pump)
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- Conclusion

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- **PumpExample2 (PrescribedPump)**
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Basic knowledge of centrifugal pump

- Centrifugal Pump state variables
- Performance curve of centrifugal pump (characteristics at standard rotation speed)
- Performance conversion formula of centrifugal pump (characteristics when rotating speed is changed)
- Parallel connection of centrifugal pumps
- Effective suction head

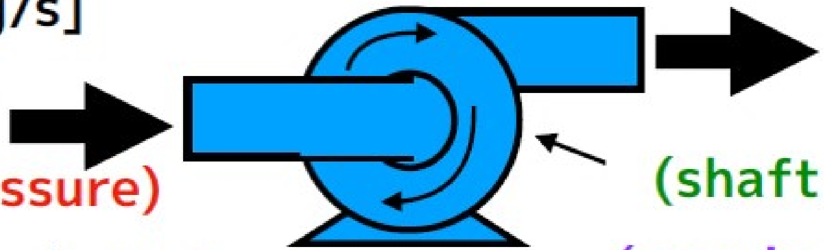
(Centrifugal pump) State variables

(mass flow rate)

m_flow_{single} [kg/s]

(discharge pressure)

$\mathrm{port\_b}.p(start = p\_b_{start})$ [Pa]



(suction pressure)

$\mathrm{port\_a}.p(start = p\_a_{start})$ [Pa]

(shaft torque) τ [Nm]

(angular velocity) ω [rad/s]

(volumetric flow rate)

$$V\_flow_{single} = \frac{m\_flow_{single}}{\rho} \quad \text{[m3/s]}$$

(rotational speed)

$$N = \frac{60}{2\pi}\omega \quad \text{[rpm]}$$

(head)

$$head = \frac{dp\_pump}{\rho g} \quad \text{[m]}$$

(pressure increase)

$$dp\_pump = port\_b.p - port\_a.p \quad \text{[Pa]}$$

(power consumption),(shaft power)

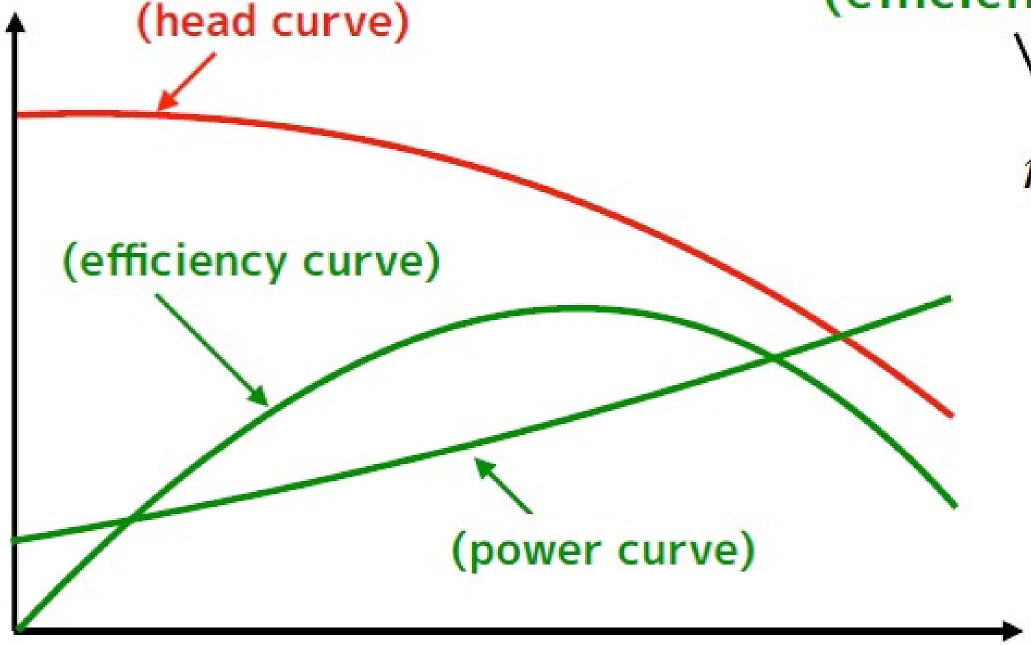
$$W_{single} = \omega\tau \quad \text{[W]}$$

$\rho = \mathrm{medium}.d$ [kg/m3] (density)

g [m/s2]: (acceleration of gravity)

Performance curve of centrifugal pump (characteristics at standard rotation speed)

Reference speed $N = N_{nominal}$ of pumps in Japan



flow rate $V\_flow_{nominal}$ [m3/s]

(efficiency)

(water power),

(theoretical power)

$$\eta = \frac{\boxed{dp\_pump \cdot V\_flow_{single}}}{W_{single}}$$

(shaft power)

These curves are data provided by the manufacturer and gained from experiments.

Either shaft power characteristic or efficiency characteristic is required

Head characteristics (head curve) $head_{nominal} = \mathrm{flowCharacteristic}(V\_flow_{nominal})$ [m]

Shaft power characteristics (power curve) $W_{nominal} = \mathrm{powerCharacteristic}(V\_flow_{noinal})$ [W]

Efficiency characteristics (efficiency curve) $\eta_{nominal} = \mathrm{efficiencyCharacteristic}(V\_flow_{noinal})$

Performance conversion formula for centrifugal pumps (characteristics when rotating speed is changed)

volumetric flow rate

$$V\_flow_{single} = \left(\frac{N}{N_{nominal}}\right) V\_flow_{nominal}$$

Speed ratio

$$\left(\frac{N}{N_{nominal}}\right)$$

(head)

$$head = \left(\frac{N}{N_{nominal}}\right)^2 head_{nominal}$$

(power consumption), (shaft power)

$$W_{single} = \left(\frac{N}{N_{nominal}}\right)^3 \frac{\rho}{\rho_{nominal}} W_{nominal}$$

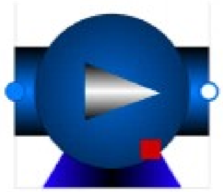
The above equation is obtained on the assumption that the efficiency η does not change even when the rotational speed changes.

$$\eta = \eta_{nominal}$$

$$\Leftrightarrow \frac{\rho \cdot g \cdot head \cdot V\_flow_{single}}{W_{single}} = \frac{\rho_{nominal} \cdot g \cdot head_{nominal} \cdot V\_flow_{nominal}}{W_{nominal}}$$

$$\Leftrightarrow W_{single} = \frac{\rho}{\rho_{nominal}} \frac{head \cdot V\_flow_{single}}{haed_{nominal} \cdot V\_flow_{nominal}} W_{nominal} = \frac{\rho}{\rho_{nominal}} \left(\frac{N}{N_{nominal}}\right)^3 W_{nominal}$$

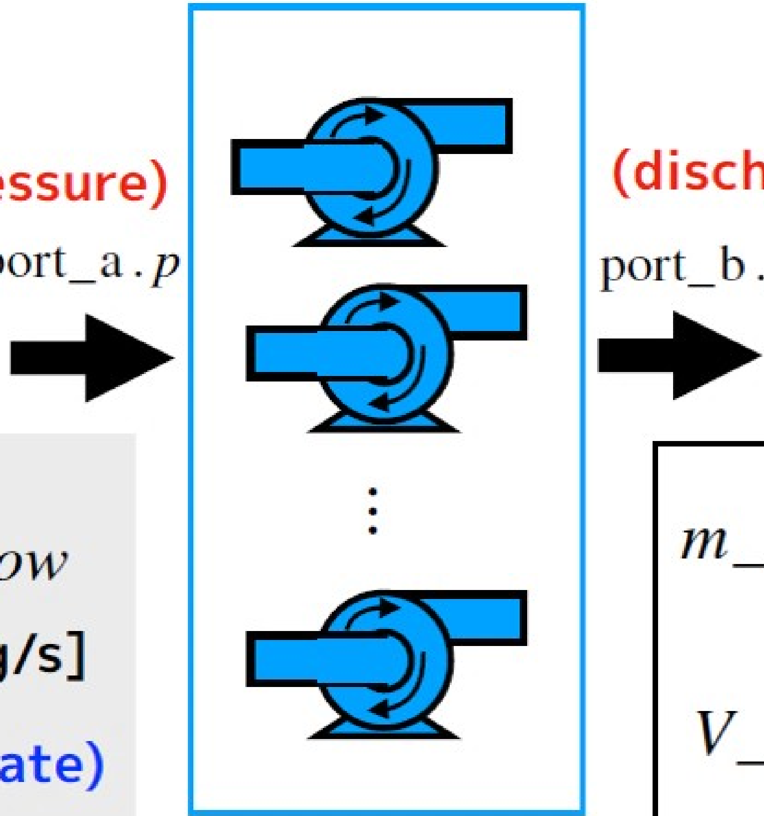
Parallel connection of centrifugal pumps



$n_{Parallel}$ **Pumps are connected in parallel.**

(suction pressure)

$\text{port\_a}.p$



(discharge pressure)

$\text{port\_b}.p$

One pump

$$m\_flow_{single} = \frac{m\_flow}{n_{Parallel}}$$

$$V\_flow_{single} = \frac{V\_flow}{n_{Parallels}}$$

$$W_{single}$$

(mass flow rate)

$$m\_flow = \text{port\_a}.m\_flow$$

$(start = m\_flow_{start})$ [kg/s]

(volumetric flow rate)

$$V\_flow = \frac{m\_flow}{\rho} \quad \text{[m3/s]}$$

(power consumption), (shaft power)

$$W_{total} = W_{single} \cdot n_{Paralel} \quad \text{[W]}$$

Method of calculating the net positive suction head (available net positive suction head)

Indicator to determine whether cavitation occurs

Calculation formula of this model

NPSPa = Inlet static pressure - Inlet saturation vapor pressure

NPDPa = Discharge port static pressure - Outlet saturation vapor pressure

NPSHa = NPSPa / (Suction port density X Gravity)

Wikipedia

https://ja.wikipedia.org/wiki/%E6%9C%89%E5%8A%B9%E5%90%B8%E8%BE%BC%E3%81%BF%E3%83%98%E3%83%83%E3%83%89

Effective suction head

It is a physical quantity indicating the difference between the pressure of the liquid in the pipe and the vapor pressure of the liquid at that temperature in an arbitrary cross section of the liquid pipe such as water or oil pressure.

$$NPSH_A = \frac{p_0 - p_v}{\rho g} + \Delta z - h_L$$

p_0 Water pressure

p_v Base pressure at liquid temperature T1

ρ Fluid density

Δz Height difference between water surface and position 1

h_L Head loss

available net positive suction head

Available effective suction head obtained by subtracting the recommended pressure head of liquid from all heads of pump suction

$$(NPSH)_{AVA} = \left(\frac{p_s}{\rho_s} + \frac{u_s^2}{2} - \frac{p_v}{\rho_s} \right) \cdot g^{-1}$$

$$= (Z_1 - Z_s) + \left(\frac{p_1}{\rho_1} - \sum F - \frac{p_v}{\rho_s} \right) \cdot g^{-1}$$

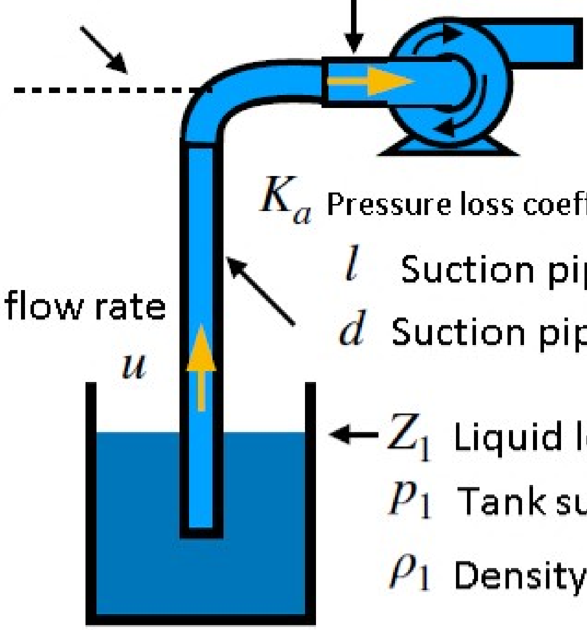
p_v Vapor pressure

p_s Suction pressure

ρ_s Suction density

Z_s Suction port height

u_s Suction flow rate



K_a Pressure loss coefficient of fittings, etc.

l Suction pipe length

d Suction pipe inner diameter

Suction pipe flow rate u

Z_1 Liquid level in the tank

p_1 Tank surface pressure

ρ_1 Density in the tank

Energy conservation equation

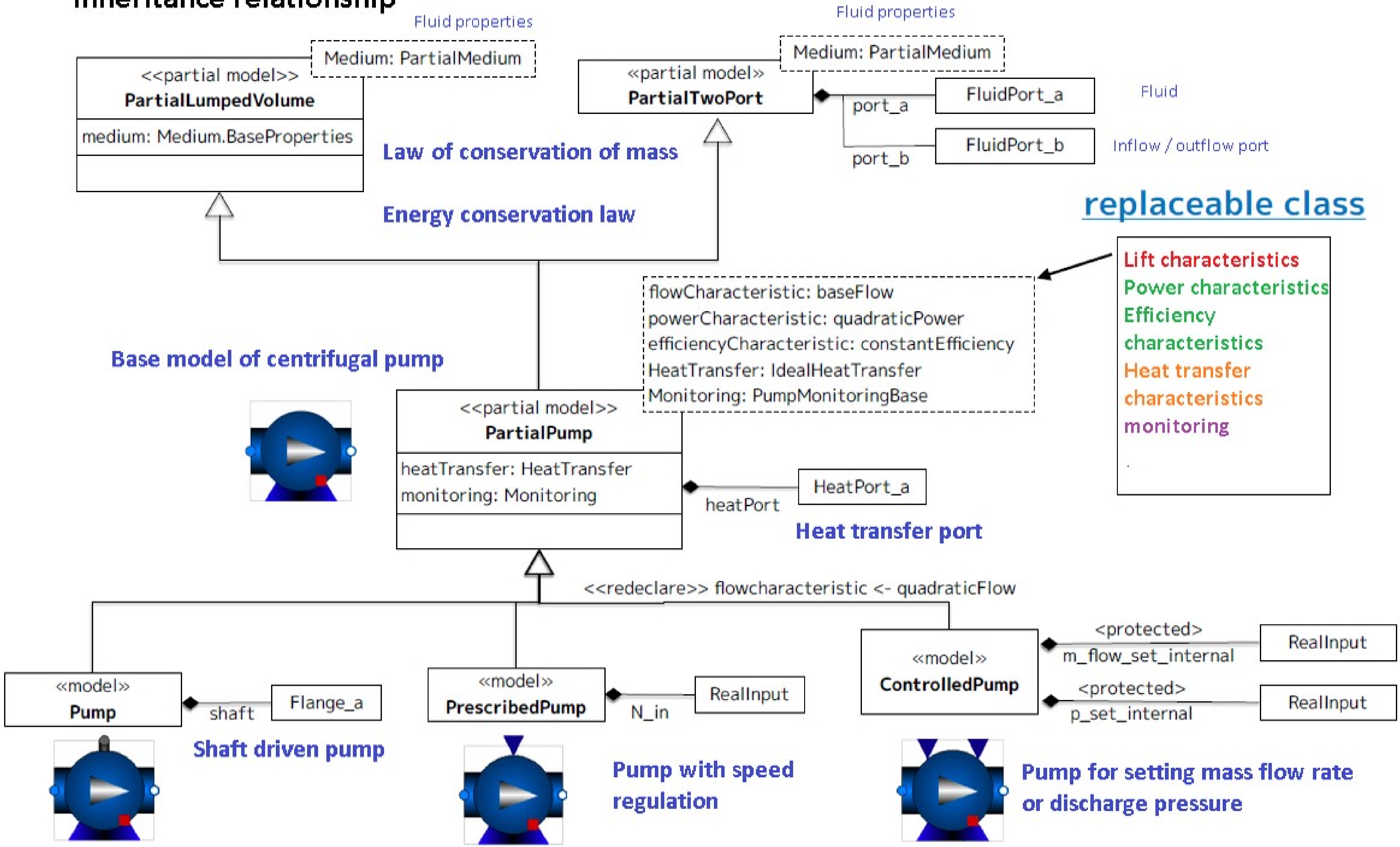
$$g \cdot Z_1 + \frac{p_1}{\rho_1} = g \cdot Z_s + \frac{p_s}{\rho_s} + \frac{u_s^2}{2} + \sum F$$

Energy lost due to friction, etc.

$$\sum F = \left(4f \cdot \frac{l}{d} + \sum K_a \right) \cdot \frac{u^2}{2}$$

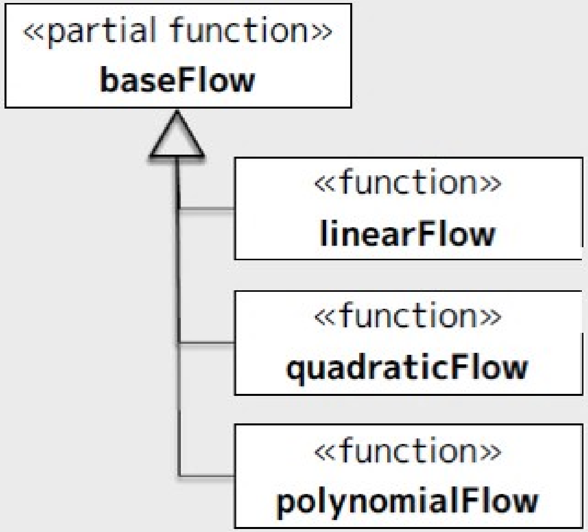
- **In the above formula, consider the path from the liquid level to the suction port**
- **There is a slightly different definition in either use the static pressure or use the total pressure of the suction port in the evaluation**

Inheritance relationship



replaceable class (1)

(head curve) Lift characteristics



Head is linear with flow

$$head_{nominal} = c_1 + V\_flow_{nominal} \cdot c_2$$

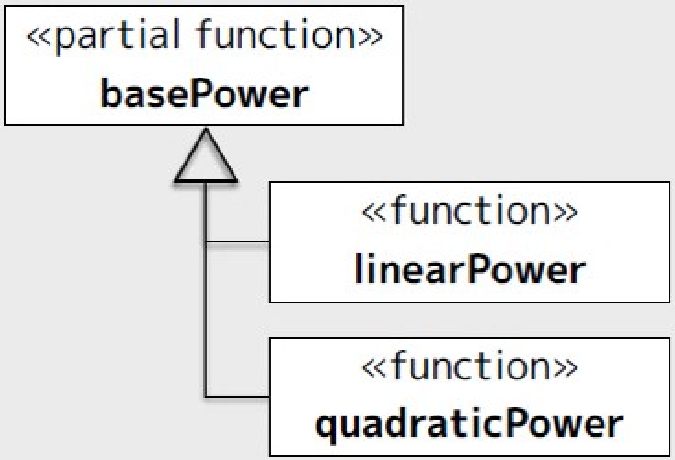
Second-order polynomial of the lift flow rate

$$head_{nominal} = c_1 + V\_flow_{nominal} \cdot c_2 + V\_flow_{nominal}^2 \cdot c_3$$

The head is the order polynomial of the flow rate

$$head = \sum_{i=1}^{n+1} V\_flow^{i-1} \cdot c_i$$

(power curve) Shaft power characteristics



Shaft power is linear with flow

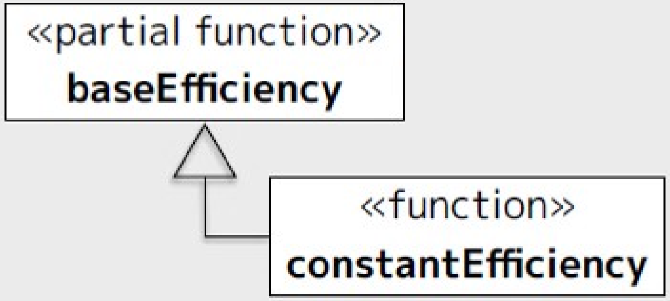
$$W_{nominal} = c_1 + V\_flow_{nominal} \cdot c_2$$

Shaft power is 2nd order polynomial of flow rate

$$W_{nominal} = c_1 + V\_flow_{nominal} \cdot c_2 + V\_flow_{nominal}^2 \cdot c_3$$

replaceable class (2)

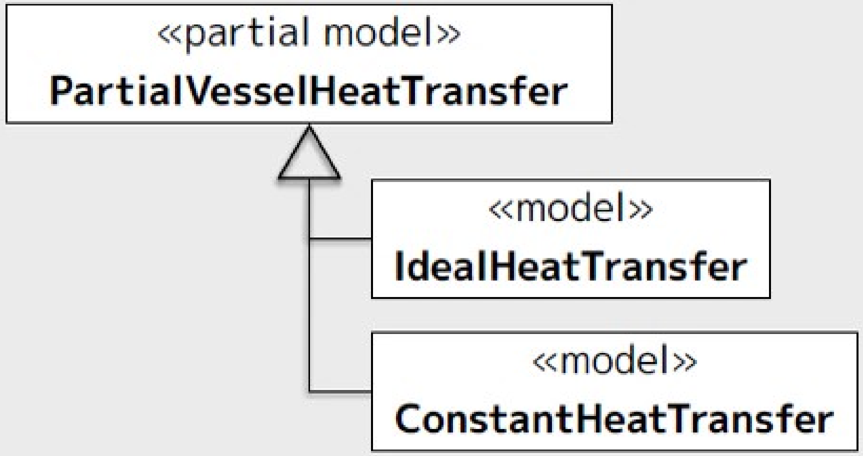
Efficiency characteristics (efficiency curve)



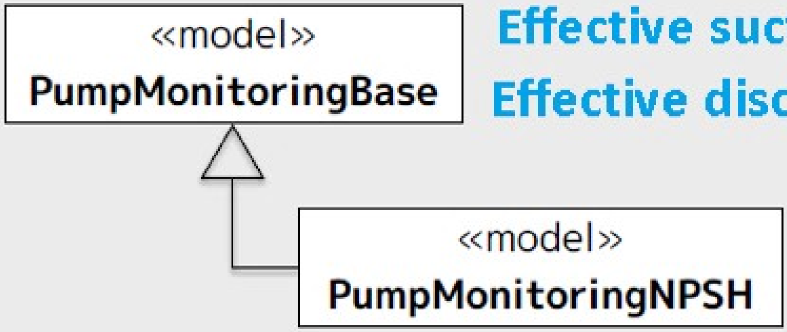
Default
$\eta = 0.8$

Efficiency is constant
$\eta = \eta_{nominal}$

Heat transfer characteristics (heat transfer)



Pump monitoring



Effective suction lift $NPSHa$

Effective suction pressure $NPSPa$

Effective discharge pressure $NPDPa$

NPSPa
Difference between inlet static pressure at inlet and saturated vapor pressure

NPDPa
Difference between static pressure at outlet and outlet saturated vapor pressure

$$NPSHa = \frac{NPSPa}{\rho_{in} \cdot g}$$

assertPositiveDifference(p, p_sat) **Algorithm**

```
algorithm
  dp := p - p_sat;
  assert(p >= p_sat, message);
end assertPositiveDifference;
```

Difference between static pressure and vapor pressure

PartialPump (Base model of centrifugal pump)

- (parameters)
- (homotopy transformation)
- actual models
- simplified models
- (mass balances)
- (energy balance)

(parameters)

Parameters	unit	unit definition	default
N_nominal	rpm	**Reference speed**	
rho_nominal	kg/m3	Reference densitv	Medum defaullt
V	m3	Pump volume	0 [m3]
nParallels	table?	Number of parallel pumps	1 [table?]
chekcValve		true: Use check valve function	false
use_PowerCharacteristic		true:Using shaft power characteristics false: Use efficiency characteristics	false
use_HeatTransfer		true: Consider heat transfer	false
show_NPSHa		true: NPSHa Output (obsolete)	false

(initial values)

$$p\_a_{start} = system\,.\,p_{start}$$ Suction pressure

$$p\_b_{start} = p\_a_{start}$$ Discharge pressure

$$m\_flow_{start} = system\,.\,m\_flow_{start}$$ Mass flow

$$V\_flow_{single\_init} = \frac{m\_flow_{start}}{\rho_{nominal} \cdot n_{Parallel}}$$

$$delta\_head_{init} = \mathrm{flowCharacteristic}(V\_flow_{single\_init}) - \mathrm{flowCharacteristic}(0)$$

Homotopy transformatior simplified

It is used in the model

(homotopy transformation)

When solving a system of nonlinear equations by iterative calculation at the initialization stage of a simulation, the model is continuously converted from a model (simplified models) from which a solution can be easily obtained to an actual model

homotopy operator

$$y = \text{homotopy}(\text{actual} = \mathit{actural}, \text{simplified} = \mathit{simplified})$$

$$\Leftrightarrow y = \mathit{actual} \cdot \lambda + \mathit{simplified} \cdot (1 - \lambda), \qquad \lambda = 0 \to 1$$

Since the formulas for flow rate, head, shaft power, and efficiency are nonlinear equations, homotopy conversion is performed.

Flow rate equation

```
// Flow equations
V_flow = homotopy(m_flow/rho,
                  m_flow/rho_nominal);
```

actual model

simplified model

actual models (1)

volumetric flow rate

$$V_{flow} = \frac{m_{flow}}{\rho}$$

$$V_{flow\_single} = \frac{V_{flow}}{nParallel}$$

Constants and the curve coordinate variables of the check valve function s

constant $\mathrm{unitHead} = 1$

constant $\mathrm{unitMassFlowRate} = 1$

final constant $\mathrm{unit\_m\_flow} = 1$

s Initial value of $s = \dfrac{m\_flow_{start}}{\mathrm{unit\_m\_flow}}$

(head)

No check valve function $checkValve = false$

$$head = \left(\frac{N}{N_{nominal}}\right)^2 \mathrm{flowCharacteristic}\left(V\_flow_{single}\left(\frac{N_{nominal}}{N}\right)\right), s = 0$$

With check valve function $checkValve = true$

$$head = \begin{cases} \left(\frac{N}{N_{nominal}}\right)^2 \mathrm{flowCharacteristic}\left(V\_flow_{single}\left(\frac{N_{nominal}}{N}\right)\right), & s > 0 \\ \left(\frac{N}{N_{nominal}}\right)^2 \mathrm{flowCharacteristic}(0) - s \cdot \mathrm{unitHead}, & s \le 0 \end{cases}$$

$$V\_flow_{single} = \begin{cases} s \cdot \frac{\mathrm{unitMassFlowRate}}{\rho}, & s > 0 \\ 0, & s \le 0 \end{cases} \Leftrightarrow s = \frac{\rho \cdot V\_flow_{single}}{\mathrm{unitMassFlowRate}}$$

actual models (2)

(power curve) (power consumption), (shaft power)

Using shaft power characteristics $use\_powerCharacteristic = true$

$$W_{single} = \left(\frac{N}{N_{nominal}}\right)^3 \frac{\rho}{\rho_{nominal}} \mathrm{powerCharacteristic}\left(V\_flow_{single} \frac{N_{nominal}}{N}\right)$$

$$\eta = \frac{dp\_pump \cdot V\_flow_{single}}{W_{single}}$$

Use efficiency characteristics $use\_powerCharacteristic = false$

$$\eta = \mathrm{efficiencyCharacteristic}\left(V\_flow_{single}\left(\frac{N_{nominal}}{N}\right)\right)$$

$$W_{single} = \frac{dp\_pump \cdot V\_flow_{single}}{\eta}$$

simplified models

(volumetric flow rate)

$$V\_flow = \frac{m\_flow}{\rho_{nominal}}$$

(head)

$$head = \frac{N}{N_{nominal}}(\mathrm{flowCharacteristic}(0) + x), \quad x = \begin{cases} \frac{V\_flow_{single} \cdot delta\_head_{init}}{V\_flow_{single\_init}}, & if\ |V\_flow_{single\_init}| > 0 \\ 0, & else \end{cases}$$

$$V\_flow_{single} = \frac{s \cdot \mathrm{unitMassFlowRate}}{\rho_{nominal}} \quad \Leftrightarrow s = \frac{V\_flow_{single}}{\rho_{nominal} \cdot \mathrm{unitMassFlowRate}}$$

(power curve) (power consumption) (shaft power)

Using shaft power characteristics

$$W_{single} = \frac{N}{N_{nominal}} \frac{V\_flow_{single}}{V\_flow_{single\_init}} \mathrm{powerCharacteristic}(V\_flow_{single\_init})$$

Using efficiency characteristics

$$\eta = \mathrm{efficiencyCharacteristic}(V\_flow_{string\_init}), \quad W_{single} = \frac{dp\_pump \cdot V\_flow_{single\_init}}{\eta}$$

Law of mass conservation (mass balances)

PartialLumpedVolume

$$\frac{dm}{dt} = mb\_flow$$ **Total mass**

$$\frac{d\mathbf{mXi}}{dt} = \mathbf{mbXi\_flow}$$ **Ingredients**

$$\frac{d\mathbf{mC}_{\mathbf{scaled}}}{dt} = \frac{\mathbf{mbC\_flow}}{C_{nominal}}$$ **Additional substances (Such as fine particles)**

- Left side is zero for stationary analysis (default)
- For a non-stationary analysis, change massDynamics and V> 0

3. Modelica.Fluid Library,
FluidExample2 volume Model reference
https://www.amane.to/wp-content/uploads/2018/12/ffe08c971d7476d067b0f2910be6dd63.pdf

PartialPump

Connect the advection term and FluidPort.

$$mb\_flow = port\_a.m\_flow + port\_b.m\_flow$$ **Total mass**

$$\begin{aligned} mbXi\_flow = & \ port\_a.m\_flow \cdot \mathrm{actualStream}(port\_a.Xi\_outflow) \\ & + port\_b.m\_flow \cdot \mathrm{actualStream}(port\_b.Xi\_outflow) \end{aligned}$$

$$port\_a.Xi\_outflow = medium.Xi$$

$$port\_b.Xi\_outflow = medium.Xi$$

Ingredients

$$\begin{aligned} mbC\_flow = & \ port\_a.m\_flow \cdot \mathrm{actualStream}(port\_a.C\_outflow) \\ & + port\_b.m\_flow \cdot \mathrm{actualStream}(port\_b.C\_outflow) \end{aligned}$$

$$port\_a.C\_outflow = C$$

$$port\_b.C\_outflow = C$$

Additional substances

Law of energy conservation (energy balance)

PartialLumpedVolume

$$\frac{dU}{dt} = Hb\_flow + Qb\_flow + Wb\_flow$$

- Left side is zero for stationary analysis (default)
- Change energyDynamics for transient analysis. Let V> {0}.

3. Modelica.Fluid Library ,
FluidExample2 volume Model reference
https://www.amane.to/wp-content/uploads/2018/12/ffe08c971d7476d067b0f2910be6dd63.pdf

PartialPump

Energy change due to work

$$Wb\_flow = W_{total}$$ (shaft power)

heatPort Heat transfer from

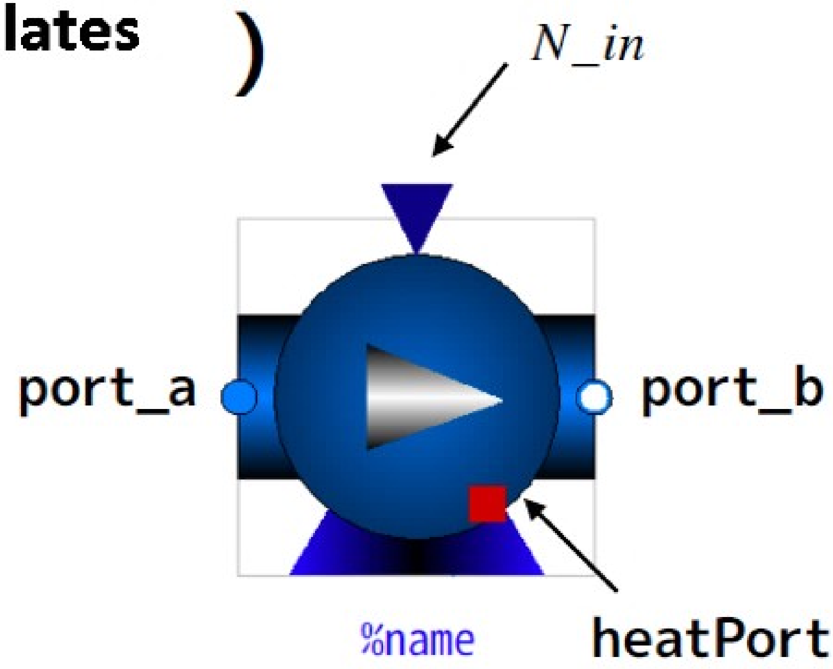
$$Qb\_flow = heatTransfer.Q_{flows}[1]$$

FluidPort Enthalpy advection from

$$\begin{aligned} Hb\_flow = \; & port\_a.m\_flow \cdot \mathrm{actualStream}(port\_a.h\_outflow) \\ & + port\_b.m\_flow \cdot \mathrm{actualStream}(port\_b.h\_outflow) \end{aligned}$$

$$port\_a.h\_outflow = medium.h$$
$$port\_b.h\_outflow = medium.h$$

PrescribedPump (Pump that regulates rotation speed)



Parameters

$use\_N\_in = true$ **Input connector** N_in **use**

$$\text{connect}(N\_in, N\_in\_internal)$$

$use\_N\_in = true$ **Parameters** N_const **use**

$$N\_ni\_internal = N\_const$$

Pump speed N [rpm] Is internally protected Declared connector $N\_in\_internal$ Is determined.

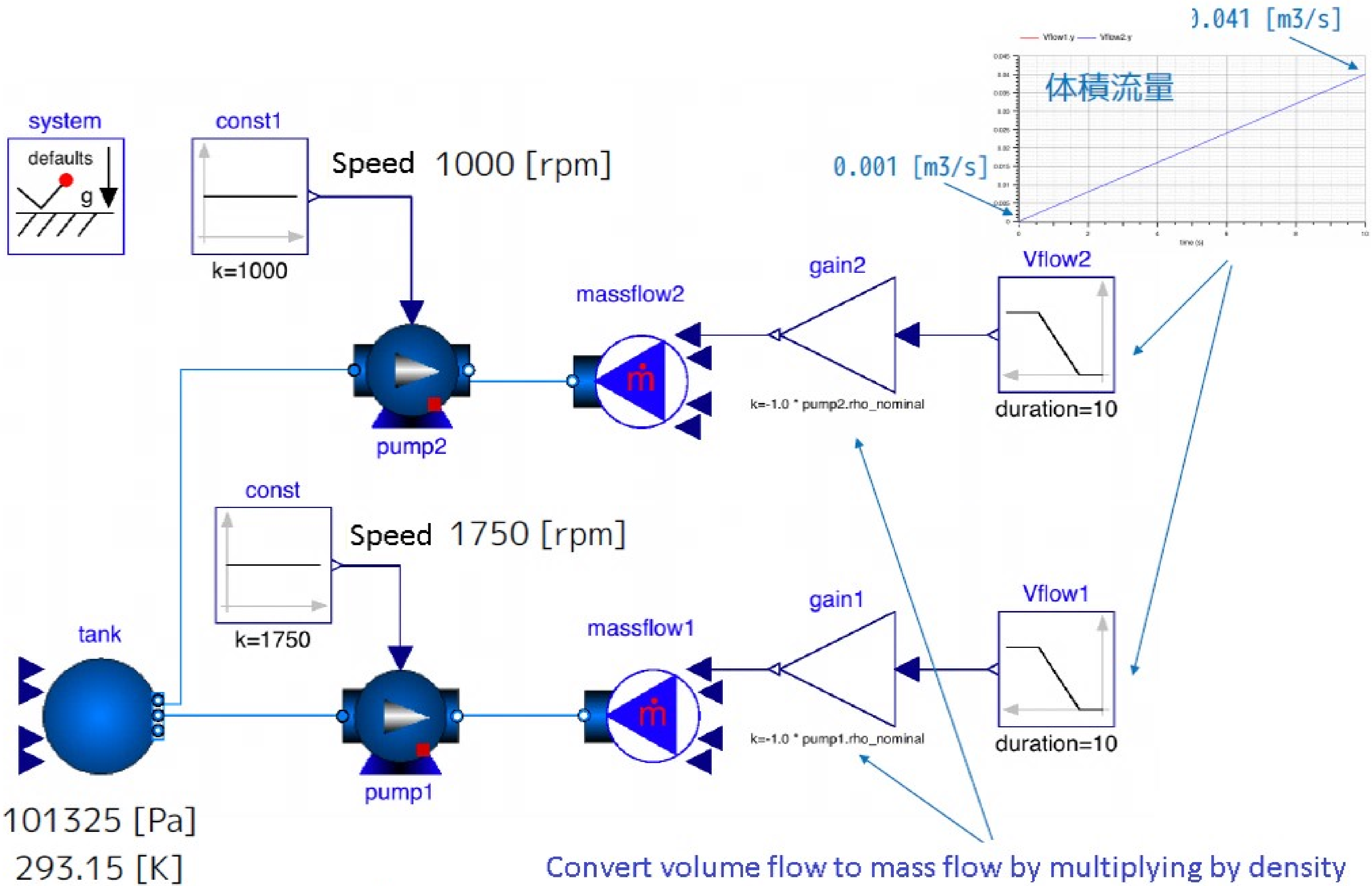
$$N = \max(N\_in\_internal, 1 \times 10^{-3})$$

Limiter (lower limit of rotation speed)

Parameters use_N_in is $N\_in\_internal$ To select the setting method

PumpExample1

PrescribedPump discharge port flow rate Change in 10 sec from 0.001 [m3/s] to 0.041 [m3/s]



With the default solver of OpenModelica (1.14.0-dev-26499-g3e12ff2), starting from a volume flow rate of 0 [m3 / s], division by zero. When starting from 0.0001 [m3 / s], the initial solution does not converge.

PrescribedPump Performance settings

Base rotation speed 1750 [rpm]

Flow rate [m3/s]	Total head [m]	Shaft power [kW]	efficiency
0.000	39.000	5.000	0.000
0.034	27.400	14.700	0.620
0.040	22.800	14.850	0.600

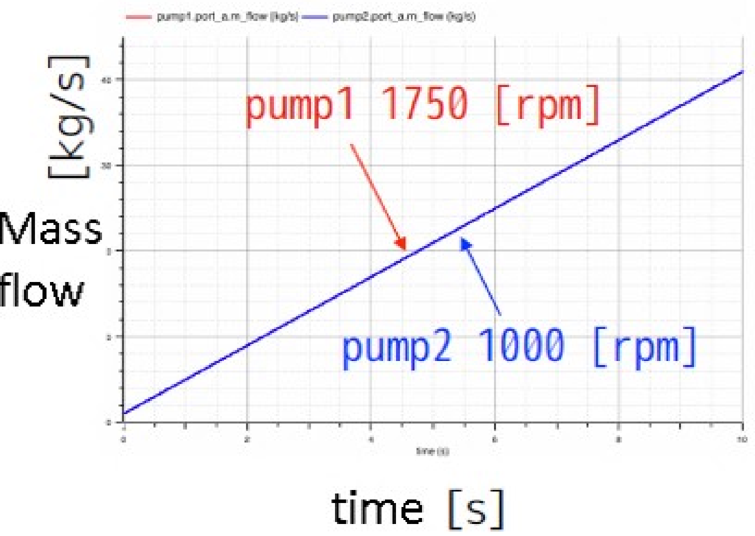
```
Modelica.Fluid.Machines.PrescribedPump pump1(
  redeclare package Medium = Medium,
  redeclare function flowCharacteristic =
    Modelica.Fluid.Machines.BaseClasses.PumpCharacteristics.quadraticFlow (
      V_flow_nominal={0,0.034,0.04}, head_nominal={39.0,27.0,22.8}),
  redeclare function powerCharacteristic =
    Modelica.Fluid.Machines.BaseClasses.PumpCharacteristics.quadraticPower (
      V_flow_nominal={0,0.034,0.04}, W_nominal={5000,14700,17000}),
  N_nominal = 1750,          Reference speed 1750 [rpm]
  checkValve = true,         Check valve function enabled
  m_flow_start = 0.0001,     Initial mass flow rate 0.0001 [kg/s]
  use_N_in = true,           To set the number of revolutions at the input connector
  use_powerCharacteristic = true) annotation( …); Use shaft power characteristics
```

Head characteristics

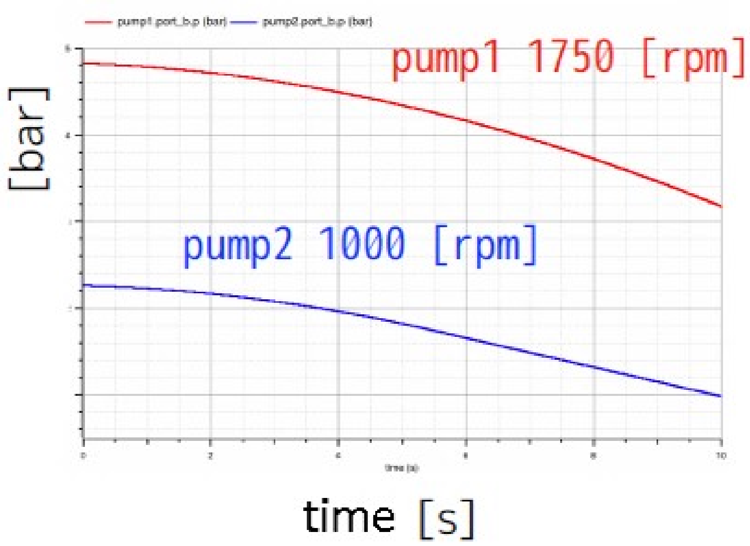
Shaft power characteristics

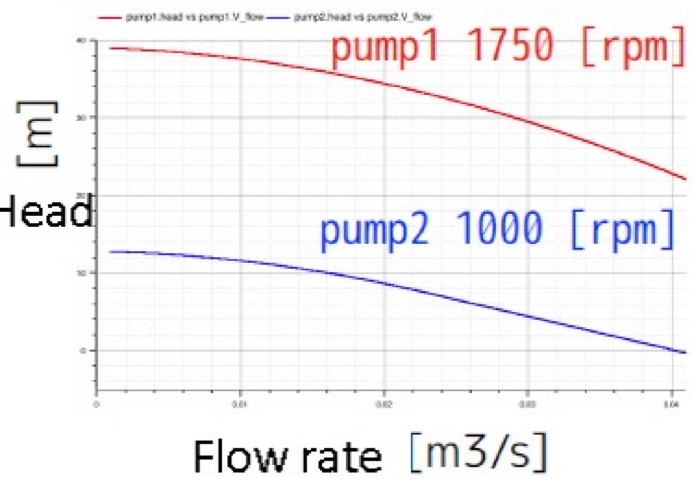
flowCharacteristic and powerCharacteristic can be exchanged for any user-defined function.

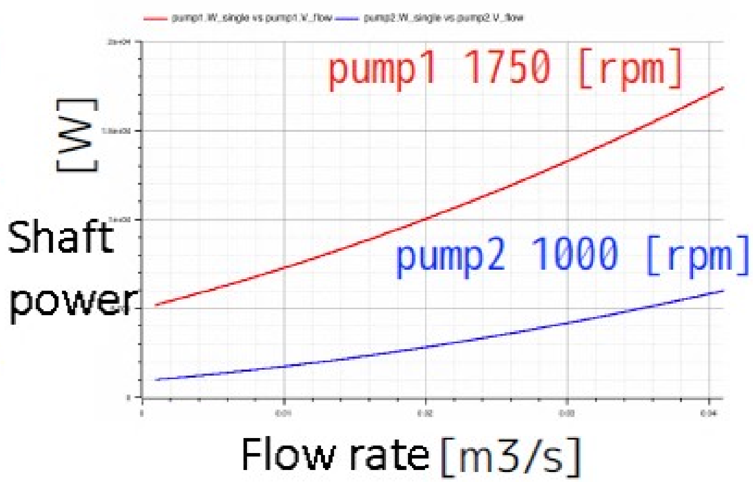
Simulation result

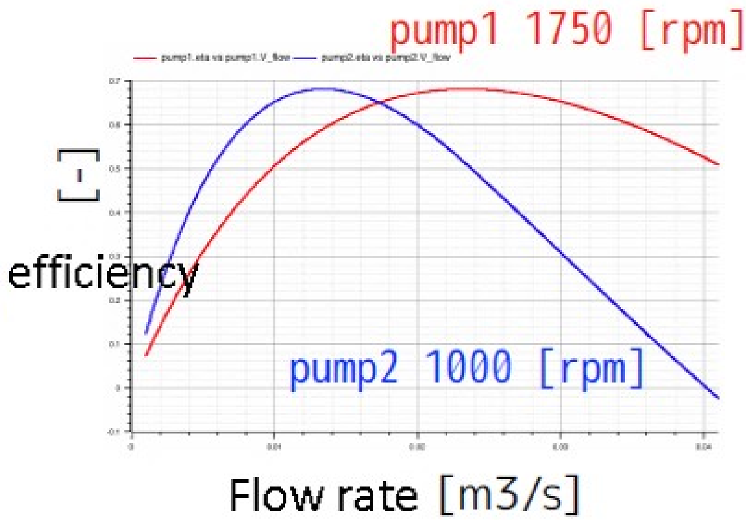


Discharge pressure



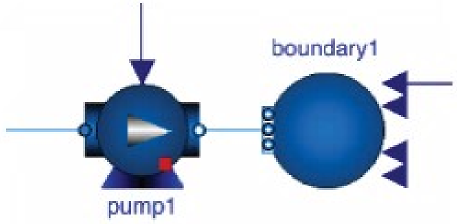






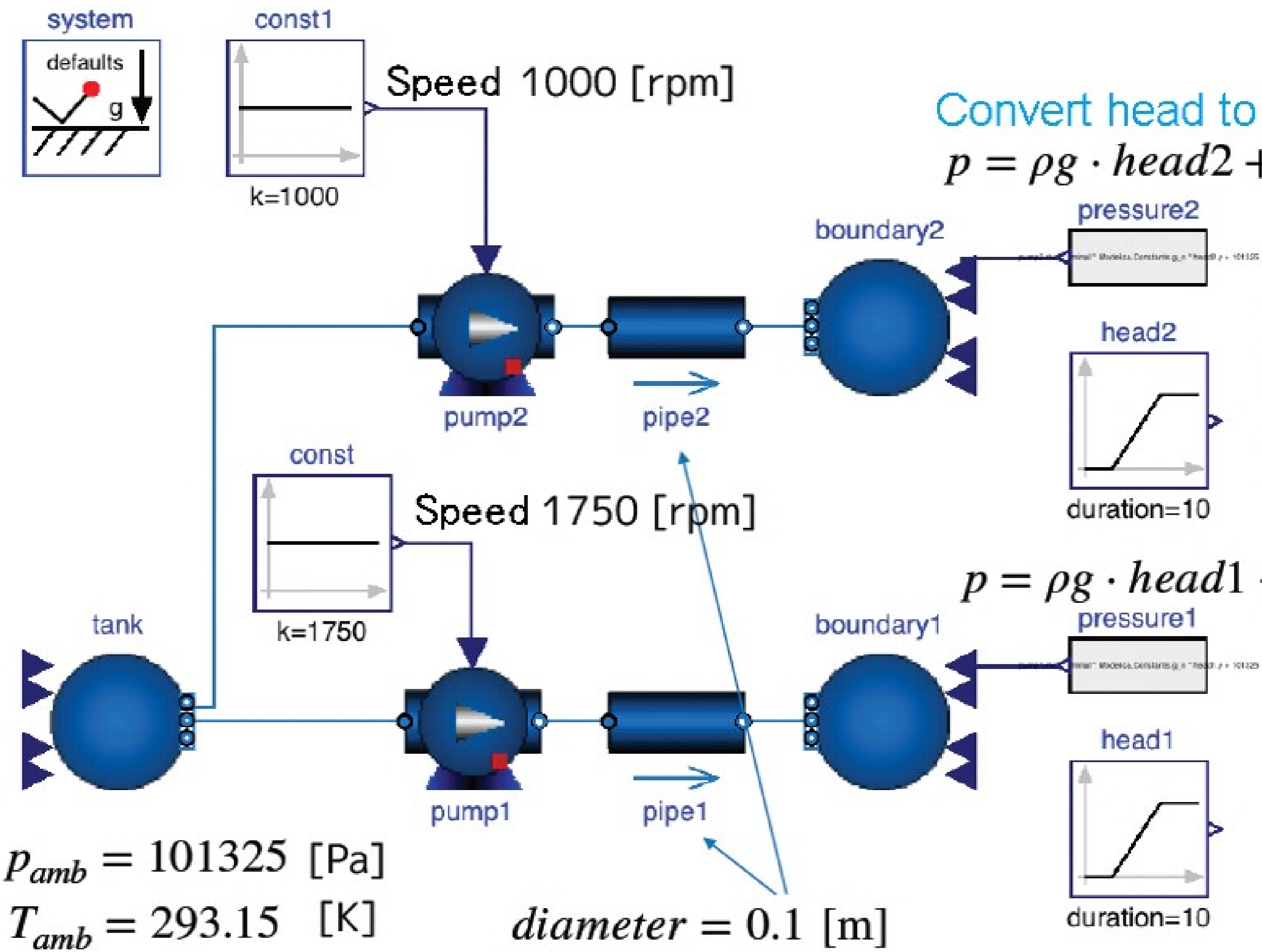
PumpExample2

When pump and Boundary_pT are directly connected, Initial solution (time = 0) is hard to converge



Connect a pipe to the outlet of the PrescribedPump to change the outlet head.

PrescribedPump The performance setting is the same as Example1.



Convert head to pressure

$$p = \rho g \cdot head2 + p_{amb}$$

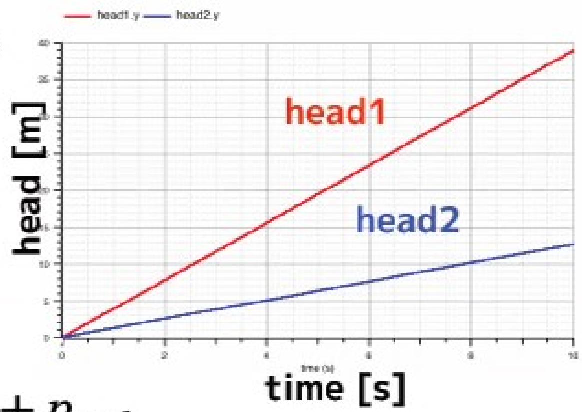
$$p = \rho g \cdot head1 + p_{amb}$$

$$p_{amb} = 101325 \text{ [Pa]}$$

$$T_{amb} = 293.15 \text{ [K]}$$

$$diameter = 0.1 \text{ [m]}$$

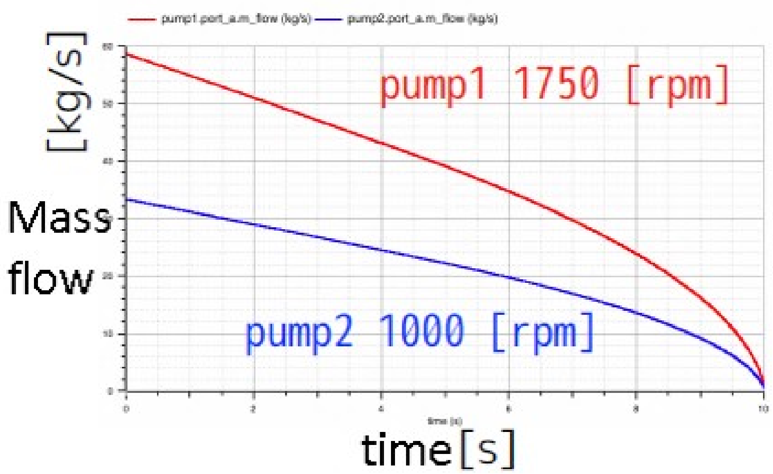
$$length = 20 \text{ [m]}$$

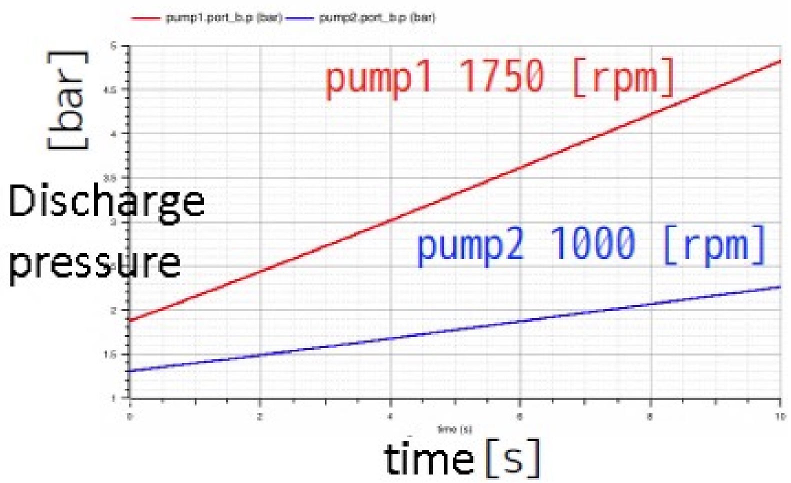


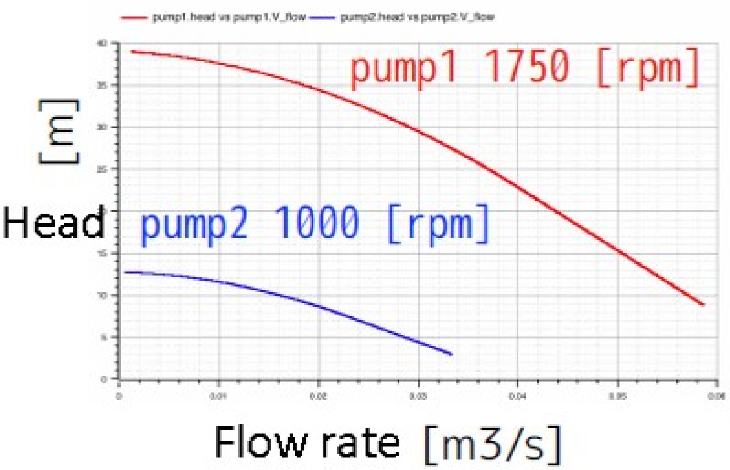
time	0 → 10
head1	0.01 → 38.91
head2	0.01 → 12.71

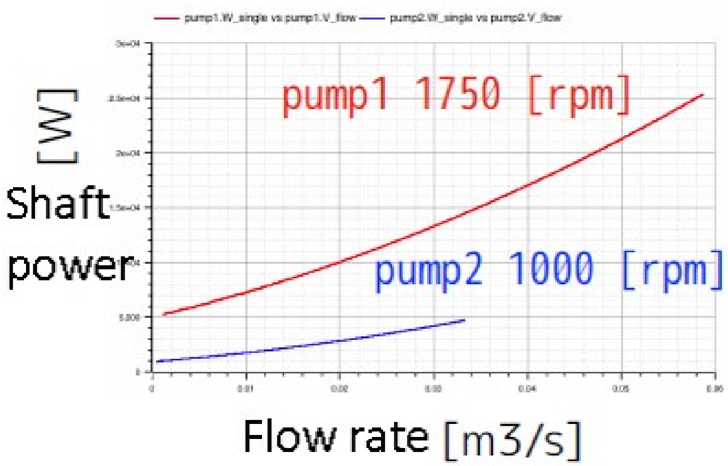
The discharge port side of the pump is internally a volume model, so connecting a flow model such as staticpipe is more stable.

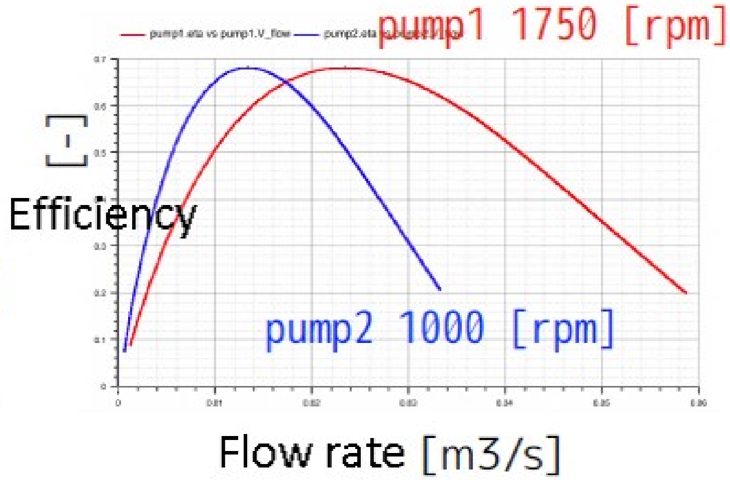
Simulation results





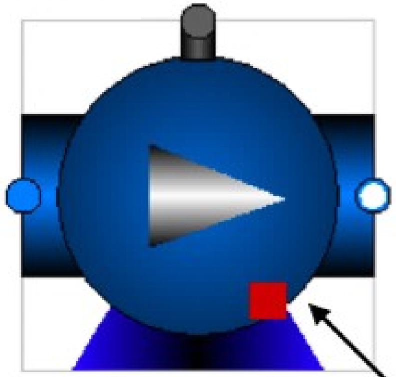






Pump (Shaft driven pump)

A pump that connects the shaft and sets the speed and power



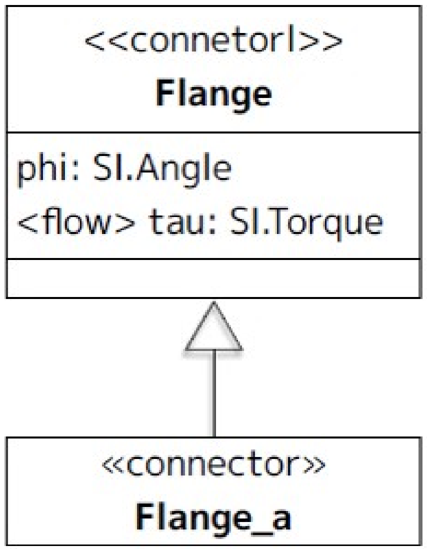
$$\varphi = shaft\,.\,phi$$ [rad]: rotation angle

$$\omega = \frac{d\varphi}{dt}$$ [rad/s]: angular velocity

$$N = Modelica\,.\,SIUnits\,.\,Conversions\,.\,to\_rpm(\omega)$$

$$W_{single} = \omega \cdot shaft\,.\,tau$$ [W]: Shaft power

$$N = \frac{60}{2\pi}\omega$$ [rpm]: Speed



Modelica.Mechanics.Rotationlas.Interfaces.Flange

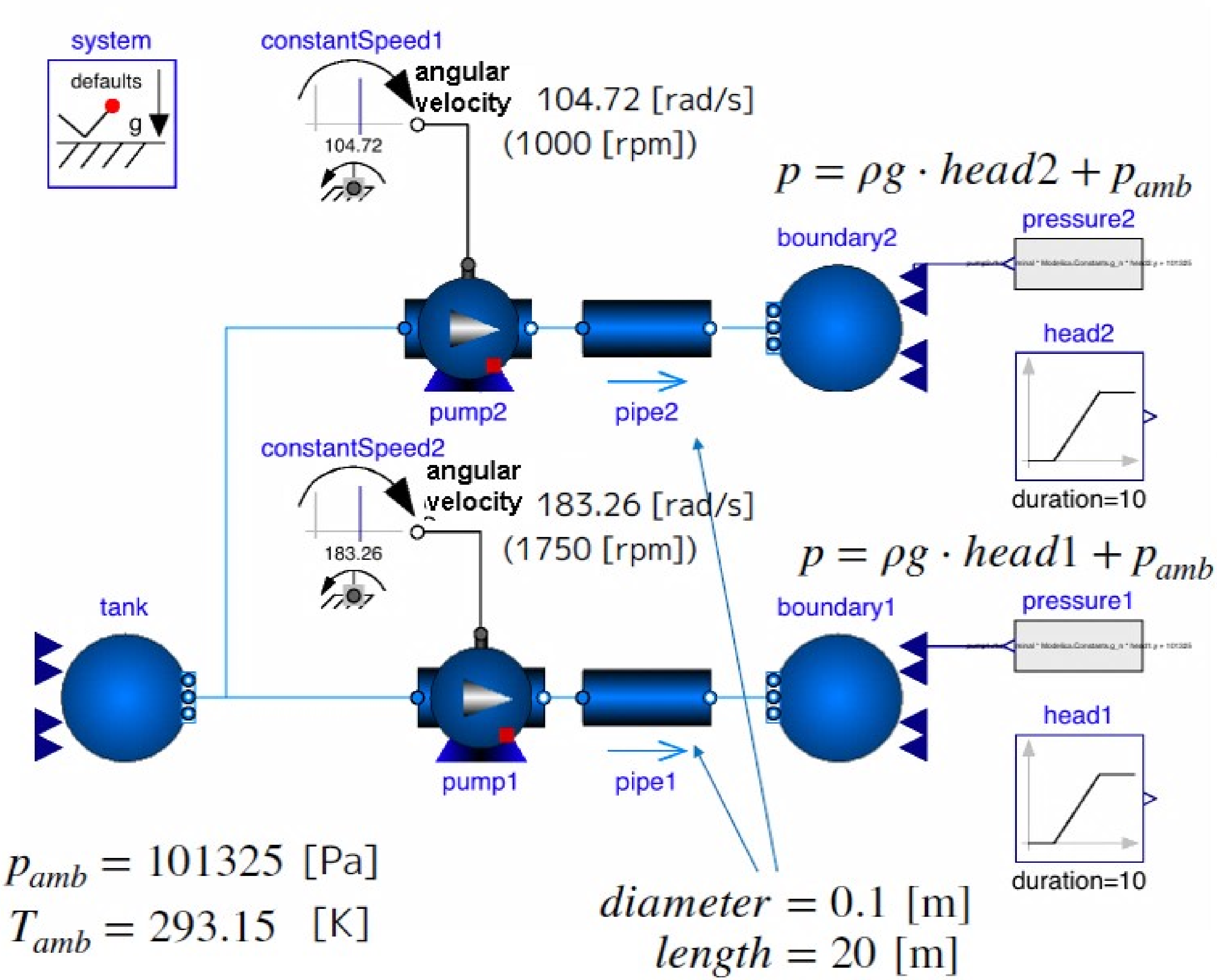
$$\varphi = shaft\,.\,phi$$ [rad]: rotation angle

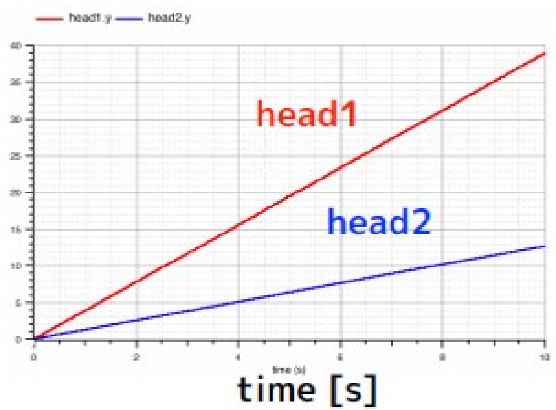
$$\tau = shaft\,.\,tau$$ [Nm]: torque

Modelica.Mechanics.Rotationlas.Interfaces.Flange_a

PumpExample3

As in PumpExample2, connect a pipe to the outlet of the Pump and change the head at the outlet.





time	0 → 10
head1	0.01 → 38.91
head2	0.01 → 12.71

Pump Performance settings

Reference speed1750 [rpm]

Flow rate [m3/s]	Total head [m]	Shaft power [kW]	efficiency
0.000	39.000	5.000	0.000
0.034	27.400	14.700	0.620
0.040	22.800	14.850	0.600

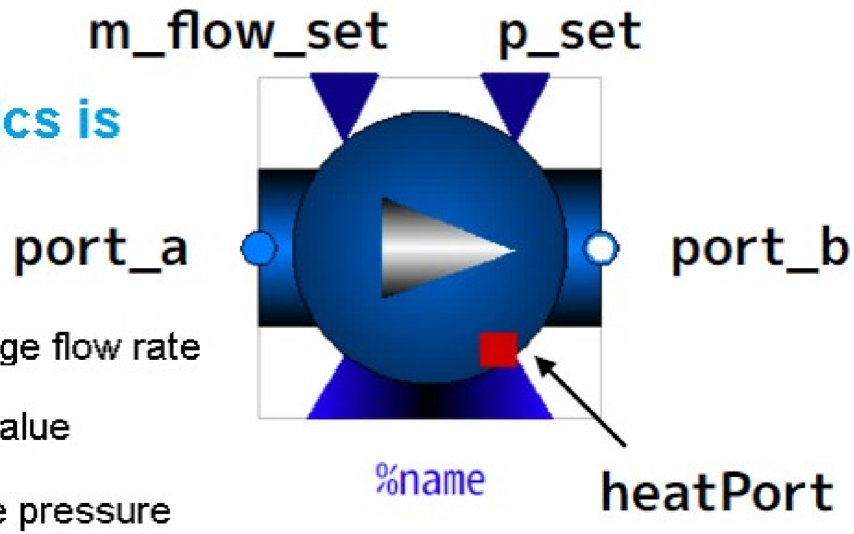
```
Modelica.Fluid.Machines.Pump pump1(
  redeclare package Medium = Medium,
  redeclare function flowCharacteristic =
    Modelica.Fluid.Machines.BaseClasses.PumpCharacteristics.quadraticFlow(
      V_flow_nominal={0,0.034,0.04}, head_nominal = {39.0,  27.0, 22.8}),
  redeclare function powerCharacteristic =
    Modelica.Fluid.Machines.BaseClasses.PumpCharacteristics.quadraticPower(
      V_flow_nominal={0,0.034,0.04}, W_nominal={5000,14700,17000}),
  redeclare model Monitoring = Modelica.Fluid.Machines.BaseClasses.PumpMonitoring.PumpMonitoringNPSH,
  N_nominal = 1750, Reference speed 1750 [rpm]
  checkValve = true, Check valve function enabled
  m_flow_start = 1,   Initial mass flow rate 1 [kg/s]
  use_powerCharacteristic = true) Use shaft power characteristics
  annotation( ⋯);
```

Lift characteristics

Shaft power characteristics

NPSHa Monitoring

ControlledPump (Mass flow rate / discharge pressure regulation pump)



Pump to set mass flow or discharge pressure

Used when the importance of pump characteristics is secondary

Pump head characteristics are parameters

$m\_flow_{nominal}$ [kg/s]: Reference value of discharge flow rate

$p\_a_{nominal}$ [Pa]: Suction pressure reference value

$p\_b_{nominal}$ [Pa]: Reference value of discharge pressure

Only to set in. (See next slide)

How to set flow rate and discharge pressure

$control\_m\_flow\_set = true$ **Control mass flow.**

$use\_m\_flow\_set = true$ If so, control with the input connector m_flow_set.

$false$ Then the mass flow becomes the parameter m_flownominal

$control\_m\_flow\_set = false$ Control the discharge pressure.

$use\_p\_set = true$ If so, control with the input connector p_set.

$false$ Then, the discharge pressure becomes the parameter p_bnominal.

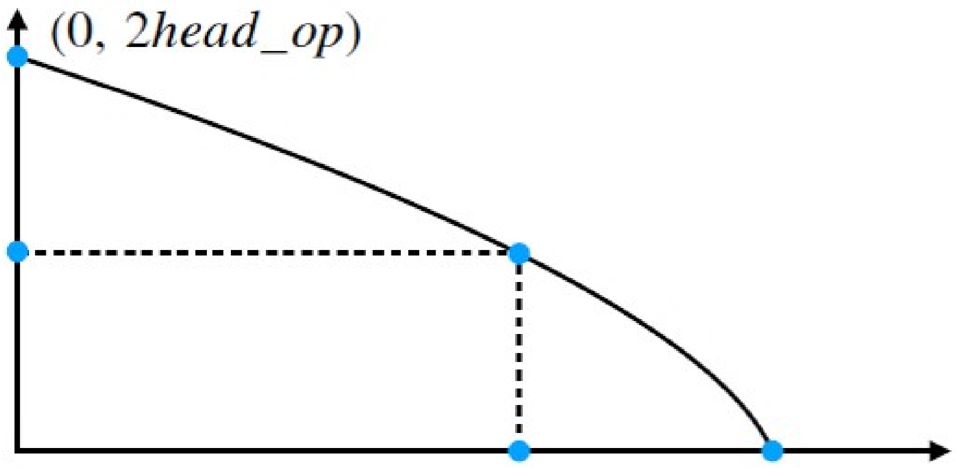
ControlledPump Head characteristics

$$V\_flow\_op = \frac{m\_flow_{nominal}}{\rho_{nominal}}$$

$$head\_op = \frac{p\_b_{nominal} - p\_a_{nominal}}{\rho_{nominal} g}$$

$$v\_flow_{nominal} = \{0, V\_flow\_op, 1.5V\_flow\_op\}$$

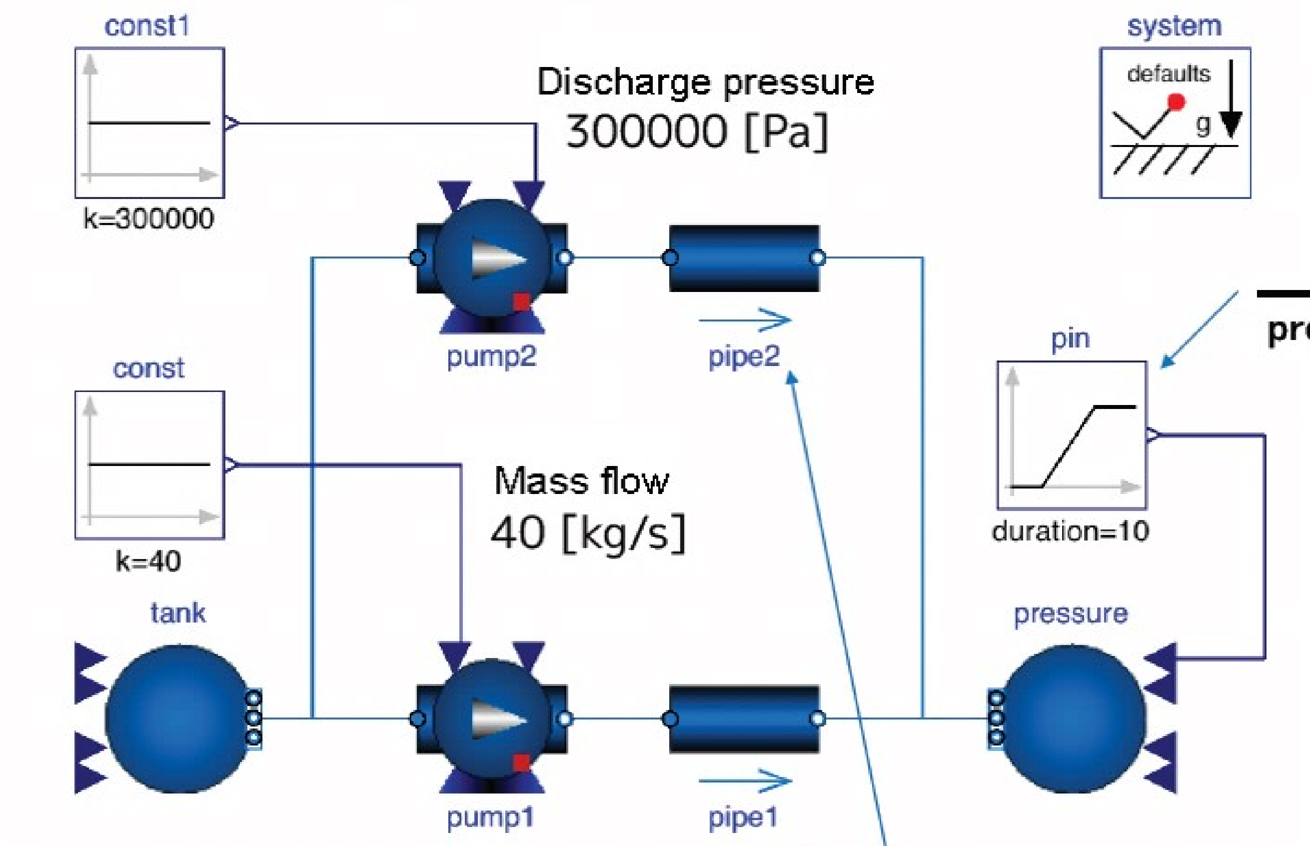
$$head_{nominal} = \{2head\_op, head\_op, 0\}$$



- The head characteristics as described above are set inside the model.
- In this model, the relationship between pressure differential and flow is determined by the piping system behind the pump.
  Do not follow this property.

PumpExample4

ControlledPump example. pump1 sets the mass flow rate to 40 [kg / s], and pump2 sets the discharge pressure to 300000 [Pa]. The pressure at the outlet of pipe1 and pipe2 is changed from 101325 [Pa] to 196325 [Pa] in 10 seconds.



time [s]	0 → 10
pressure [Pa]	101325 → 196325

$p_{amb} = 101325$ [Pa]

$T_{amb} = 293.15$ [K]

$$diameter = 0.1 \ [\mathrm{m}]$$
$$length = 20 \ [\mathrm{m}]$$

ControlledPump Performance settings

pump1 setting Specify the mass flow rate with the input connector

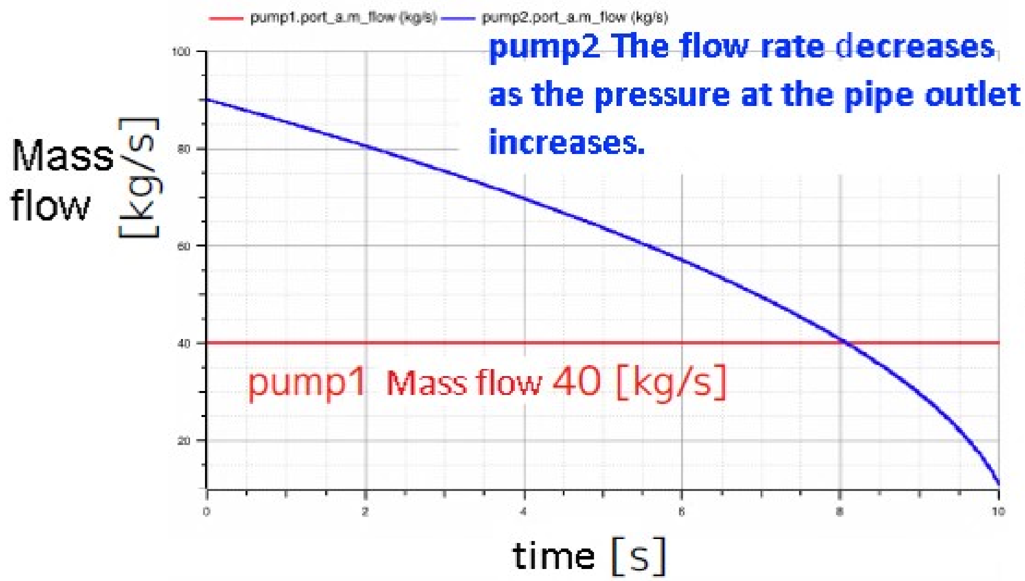
Specify the flow rate (control_m_flow = true by default)

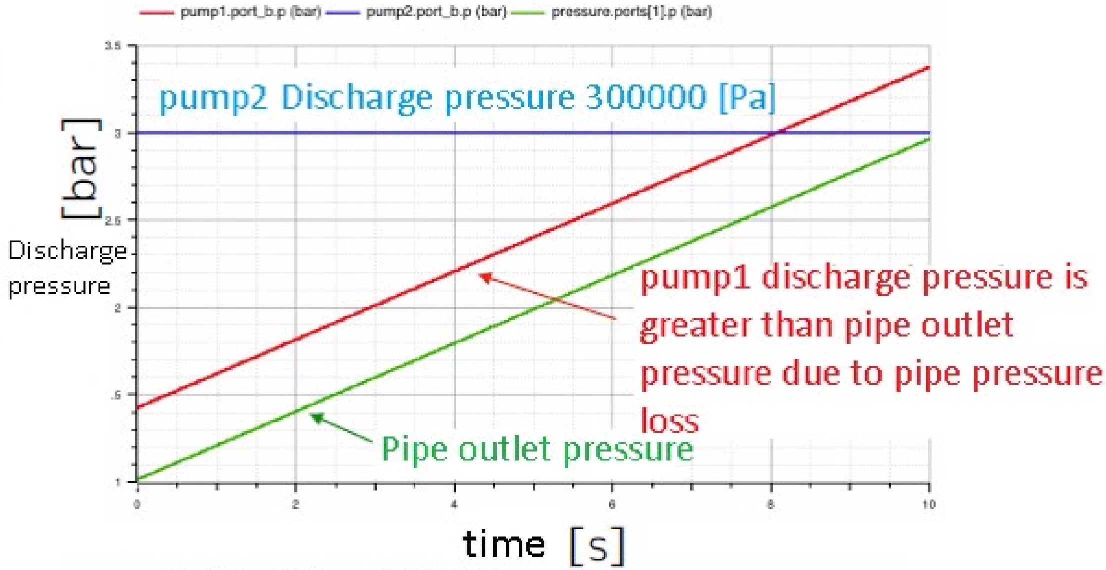
```
Modelica.Fluid.Machines.ControlledPump pump1(
  redeclare package Medium = Medium,
  m_flow_nominal = 40,        [kg/s]: Reference value of discharge flow rate
  p_a_nominal = 101325,       [Pa]: Suction pressure reference value
  p_b_nominal = 351325,       [Pa]: Reference value of discharge pressure
  use_m_flow_set = true)  Use mass flow input connectors
  annotation( …);
```

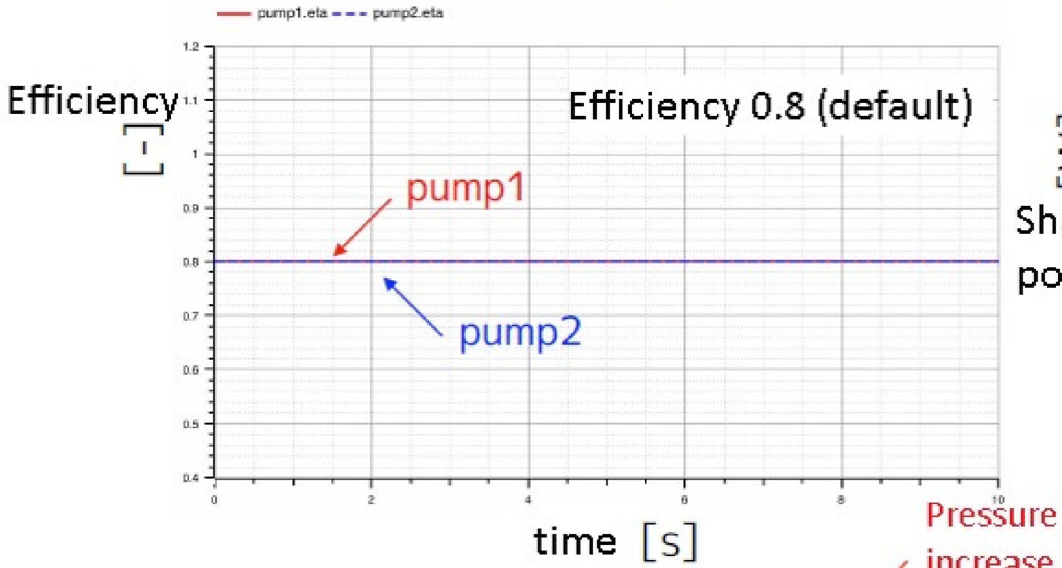
pump2 setting Input connector regulates discharge pressure

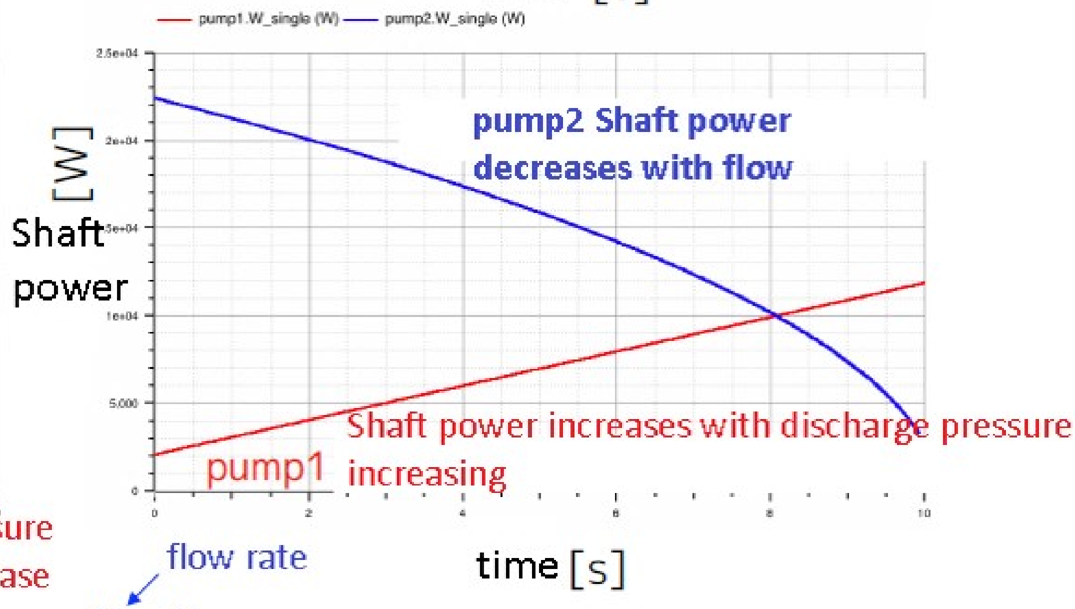
```
Modelica.Fluid.Machines.ControlledPump pump2(
  redeclare package Medium = Medium,
  control_m_flow = false, ← Specify pressure
  m_flow_nominal = 40,        [kg/s]: Reference value of discharge flow rate
  p_a_nominal = 101325,       [Pa]: Suction pressure reference value
  p_b_nominal = 351325,       [Pa]: Reference value of discharge pressure
  use_p_set = true) Use input connector for discharge pressure
  annotation(…);
```

simulation result









Pressure increase

flow rate

efficiency

$$\eta = \frac{dp\_pump \cdot V\_flow_{single}}{W_{single}}$$

Shaft power

Conclusion

The Modelica.Fluid.Machines pump model models the operation of the pump using a head characteristic and a shaft power characteristic or an efficiency characteristic.

- The head characteristic, head power characteristic, and efficiency characteristic are replaceable functions and can be replaced with user-defined functions.
- The discharge side of the pump is a volume model. By setting the pump volume V [m3], massDynamics, and energyDynamics as parameters, unsteady mass conservation and energy conservation can be considered.
- Calculations such as NPSHa can be made by setting a Monitoring model.
- Pump can connect to Modelica.Mechanics.Rotational Flange connector.
- Specify the rotation speed with PrescribedPump, Real connector or parameter.
- ControlledPump is used when the characteristics of the pump are not sufficient, and specifies the mass flow rate or discharge pressure.