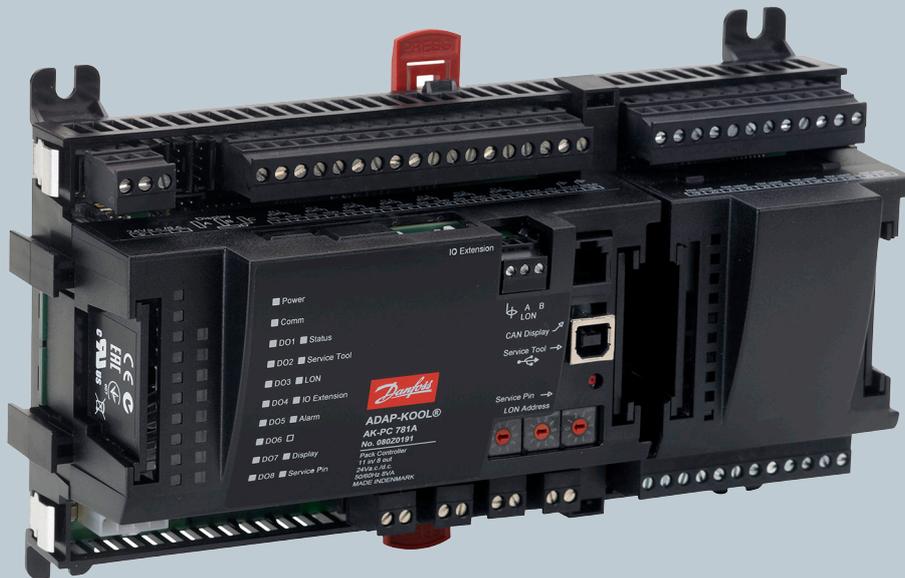*Danfoss*

Application guide

General PI controllers
Quick settings in the
AK-PC 7xxA serie

ADAP-KOOL® Refrigeration control systems

General description

This guide will help you setting up some additional controls in your refrigeration systems using the general PI controllers in the AK-PC 781A, AK-PC 782A, AK-PC 783A and AK-PC 772A. The user interface in the AK-LM 340 is slightly different.

The default settings for the general PI controller with standard applications may vary slightly from the examples in this document.

Preface

During the last years after we released the AK-PC 781 controller with general free configurable PI controllers we have seen that the free PI controllers are hard to handle. Nevertheless the general PI controllers are very flexible and can solve many additional control problems seen in refrigeration systems.

We will in this document try to explain the use of the PI controllers by showing some application examples.
The PI controllers also includes an alarm, this will not be covered by this note. The alarm is similar to all the other alarm features in the AK- platform.

General P and PI control:

The PI controllers are very flexible. They can be used as a simple P (proportional) controller to control simple systems or transform input signals, or advanced PI controls with 2 inputs.
Always consider – do I need a PI controller? could I do with a P controller (Proportional controller). Keep it simple.
A P-controller can do other things than controlling. A simple P controller can transform an input signal to a linear output signal. Fx convert a 0-10 volt signal into a 3-7 volt output or a PWM signal for an AKV valve. Any linear transformation is possible as long as we support the input and the output signal.
We will cover some examples of transformation like generating a ambient temperature voltage compensation.
Very often you don't need PI control but a simple P controller can be sufficient. P controlers are often more simple and the risk of making an unstable system is reduced. However sometimes you need the PI control in case offset free reference tracking is needed.

PID controllers are not supported because setting up a PID controller is much more complex than setting up a PI, and if you do not have full understanding of your process and the necessary skill to adjust the PID controller the result is very often more problems.

Most of the problems with PI control is caused by poor understanding of the proces. Controlling the process in the normal working range is often simple, but when the process is out of this range, like in startup situations, limitations (the actuator might be in fully open or fully closed position), problems starts. PI controllers have a hard time to cope with is time delays. If the input signal is delayed 60 sec it's very hard to make a PI controller work.
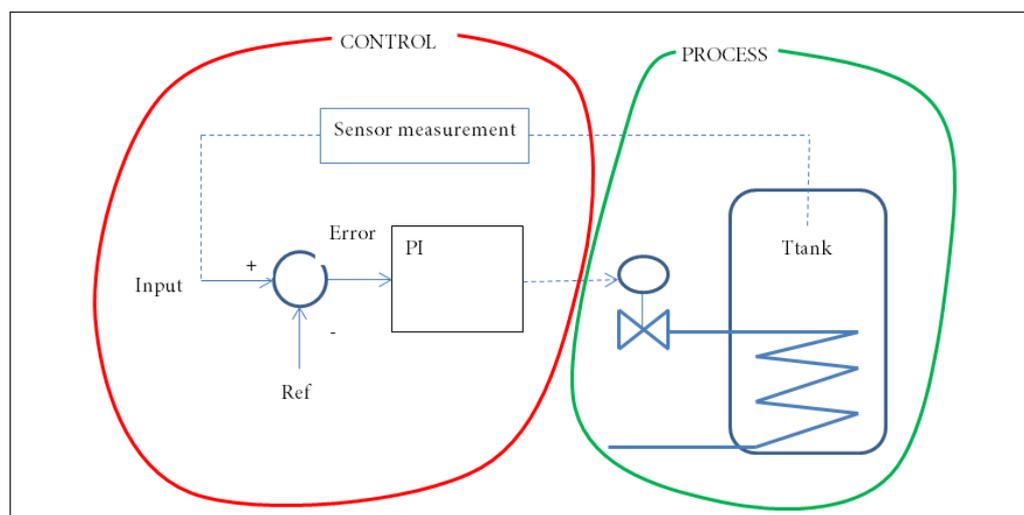
The controller will try to manipulate the process by changing its output signal in such a way that the input (fx a Tank temperature) becomes equal to the Ref (setpoint).

PI controller terms:

$$Output = E * Kp + \frac{Kp}{Tn} \int (E)\, dt$$

$$E = Input - Ref$$

Input   The controller input value. Could be a temp, Pressure, voltage, or %.

Ref   The setpoint for the controller. When the PI control is working the input should become identical to the Ref.

Output   The controller output is ALWAYS seen as %. The output is then put into hardware as a voltage, stepper motor etc.

Kp   The proportional factor often called the "gain".

Tn   The integral time constant in seconds.

The system have limitations. The output cannot exceed 0 and 100 % (a valve cannot close beyond 0%), often the input signal have limitations (a transmitter cannot exceed its range, or a temperature can't exceed a certain temperature). Very often problems are related to the limitation in the system, and should hence be carefully evaluated.

Take care

Always carefully consider the time constant in your system. Ask: How long time will it take to heat up the system (or cool down etc). If it take 3 hours to heat up the room you're controlling, the time constant is in that range of 2 (around 2/3 of 3 hours = 2).
Also take very much care about time delay. A time delay could be the time it takes to transport flow in a pipe (if you got 300 m pipe and the flow speed is 1 m/s then it takes 300 sec before a temperature change is visible in the other end. Time delays is VERY difficult to handle in normal PI controllers and could cause very much instability. Take care about time delays. Place your sensors to minimize time delays.
Avoid "windup". PI control is generally simple as long as your system is linear, the problems comes when you hit nonlinearities like satuation. A saturation occurs when there is no responding in the output from the process even you change the input. This could be something as simple as an overdimensioned valve. (ie, A valve is very big compared to what it should be and it doesn't matter if it 25% open or 100% open, the flow is at max anyway). This will cause serious problems sooner or later.

The PI controller will handle windup, but you can make some settings that reduces the risk.
Starting a PI controller is always a problem. If you got a good idea of what the output will be at the end the controller could be started at this value. The controller have the possibility to start at a fixed output and stay at that value for a startup period. This is particular usefull when the system changes fast when started (a evaporator starting from pumpdown).
Limitations on the error signal is another possibility. If your sensor input could attain low/high values when the system is OFF this could cause problems during startup. You can limit the error signal to +/- "Max error". Normally it doesn't give sense to feed a controller with values higher than the proportional part. Limit "Max Error" to Max error = "Max Output" / abs(Kp).
The PI (or P) controller can take an additional input for generating the reference.
This gives the possibility to make a controller with variable reference given by an external signal of a controller that controls e.g. a differential temperature or pressure.
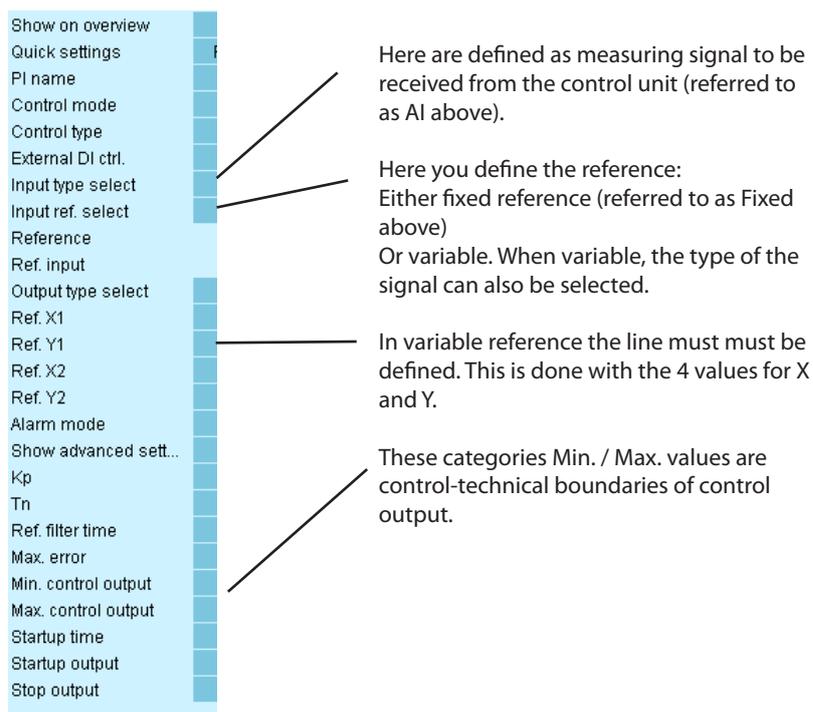
Reference
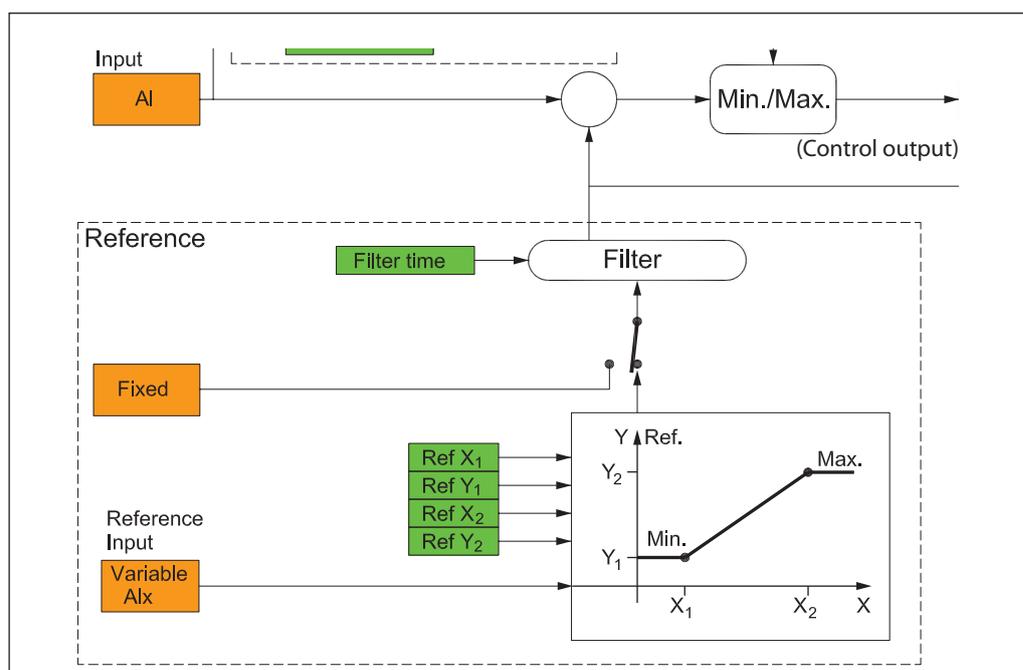
The reference can be either fixed or variable. For fixed reference a value must be set in the "Setpoint".
When variable, receiving a variable signal of some type.
This signal is converted to a reference signal and then compared with the signal from it to be controlled.

This conversion happens after a line between two points. X1, Y1 and X2, Y2.
The reference is kept within the Y values, thus indicating Min. and Max. reference.

About settings

Here are defined as measuring signal to be received from the control unit (referred to as AI above).

Here you define the reference:
Either fixed reference (referred to as Fixed above)
Or variable. When variable, the type of the signal can also be selected.

In variable reference the line must must be defined. This is done with the 4 values for X and Y.

These categories Min. / Max. values are control-technical boundaries of control output.

Applications

The following section will show some examples on how to use the PI controls.
The examples are divided into groups that gradually becomes more and more complex.

The first thing you should do is to draw a small sketch on your system. No matter how simple your system seems, make a sketch!

Simple P control	
Simple PI control	
Simple Heat control	A simple heating controller that decrease heating power for increasing temperature
Cooling control	A simple cooling controller that increase cooling power for increasing temperature
Heat control with Ambient compensated heat	Ambient temperature compensated heating controller
Pump control delta P	Fixed delta P pump control.
De-superheater	Booster desuperheater (LT discharge desuperheater)
Floor heat with Ambient compensation	Heating controller with ambient temperature compensation curve.
Dry cooler + 3 way valve	
Dry cooler + Fan control	
Simple SH control	
Signal converter	Voltage to valve open degree. Temperature to voltage output

Temperature control

Here, there are two simple guides that control the temperature by varying the opening degree of a valve.

Simple P control

Show on overview	No
Quick settings	Simple P
PI name	General PI 1
Control mode	OFF
Control type	P
External DI ctrl.	No
Input type select	Temperat...
Input ref. select	Fixed ref.
Setpoint	0.0
Reference	4.9
Output type select	PWM
Alarm mode	OFF
Show advanced settings	No

Simple PI control

Show on overview	No
Quick settings	Simple PI
PI name	General PI 1
Control mode	OFF
Control type	PI
External DI ctrl.	No
Input type select	Temperature
Input ref. select	Fixed ref.
Setpoint	10.0
Reference	10.0
Output type select	PWM
Alarm mode	OFF
Show advanced sett...	No

Simple heat controller:
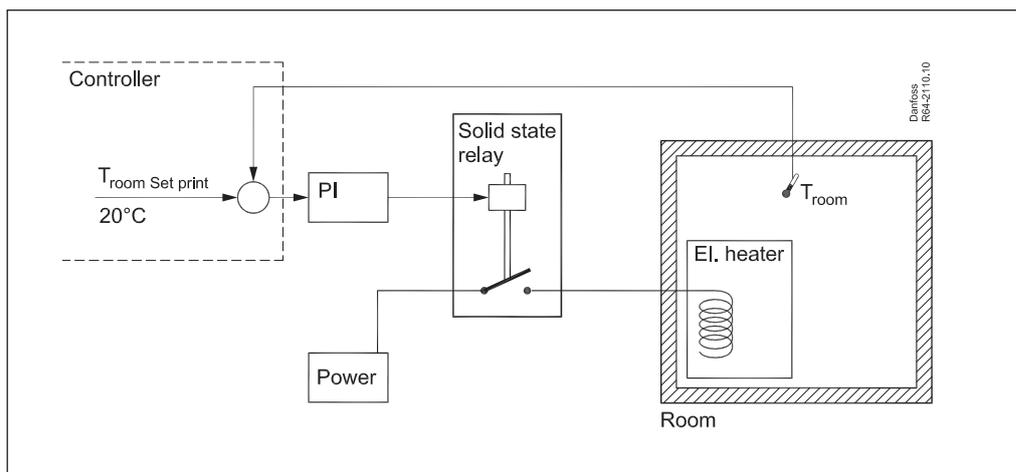
• Control Room temperature to 20°C.
• An electrical heater is placed in the room.
• The electrical power is controlled by an external solid state relay.
• A temperature sensor (Troom) is placed in the room.

Show on overview	No
Quick settings	Heat control
PI name	General PI 1
Control mode	OFF
Control type	PI
External DI ctrl.	No
Input type select	Temperature
Input ref. select	Fixed ref.
Setpoint	20.0
Reference	11.3
Output type select	PWM
Alarm mode	OFF
PWM period time	6 s
Show advanced sett...	No
Kp	-5.0
Tn	600 s
Ref. filter time	60 s
Max. error	20.0
Min. control output	0 %
Max. control output	100 %
Startup time	10 s
Startup output	30 %
Stop output	0 %

Settings

Input type is "Temperature".

Fixed reference

Reference (setpoint), here 20°C.

Output type is "PWM", this will give you an solid state output.

Kp is -5 (%/K) The output will increase/ decrease 5% for each degree you're away from the Reference.
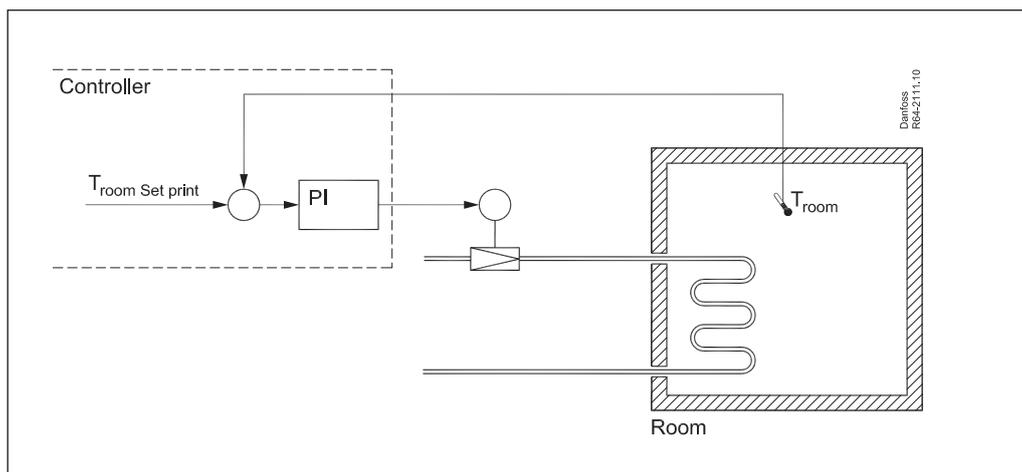
Tn (integral time in Sec): 600 sec.

As the last thing set the Control mode to "Auto".

The rest of the settings we'll leave as default.
These settings are ment for more advanced cases.

Configure the IO and switch the mainswitch ON.

Cooling room

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- Maintain a room temperature at 2°C
- Controlling a brine flow to a cooling coil.
- The flow is controlled by a 0 - 10 V valve. 10 V is fully open valve.
- A temperature sensor (Troom) is measuring the temperature in the room.

Show on overview	No
Quick settings	Cooling control
PI name	General PI 1
Control mode	OFF
Control type	PI
External DI ctrl.	No
Input type select	Temperature
Input ref. select	Fixed ref.
Setpoint	2.0
Reference	2.4
Output type select	Voltage
Alarm mode	OFF
Show advanced sett...	No
Kp	5.0
Tn	600 s
Ref. filter time	60 s
Max. error	20.0
Min. control output	0 %
Max. control output	100 %
Startup time	10 s
Startup output	30 %
Stop output	0 %

Settings

Input type is "Temperature".

Fixed reference

Reference (setpoint), here 2°C.

Output type is "Voltage".

Kp is +5 (%/K) The output will increase/ decrease 5% for each degree you're away from the Reference.
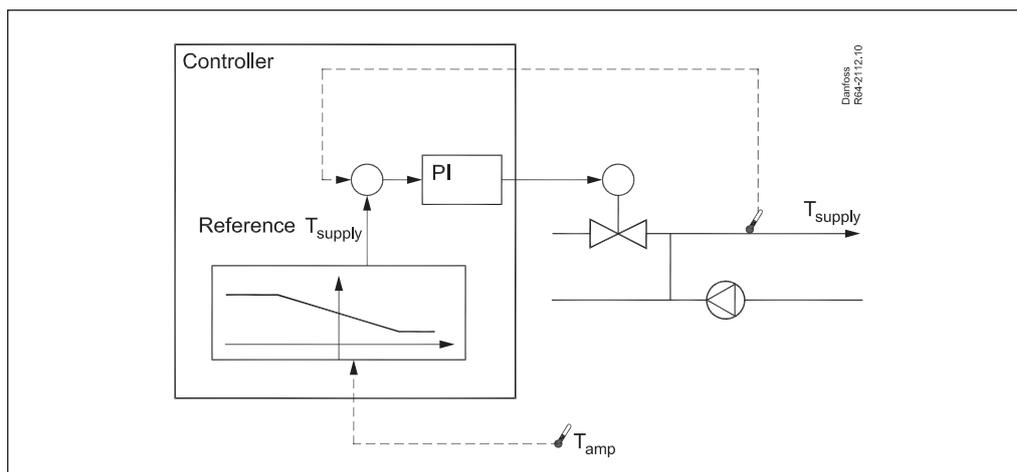
Tn (integral time in Sec): 600 sec.

As the last thing set the Control mode to "Auto".

The rest of the settings we'll leave as default. These settings are ment for more advanced cases.

Configure the IO and switch the mainswitch ON.

Heating w. ambient compensation

- Control the forward temperature in a brine loop
- An ambient temperature compensated controller. An application could be controlling the forward temperature from a Heat recovery system.
- The supply temperature we want is:
  20°C when the ambient temperature is 20°C
  55°C when the ambient temperature is -20°C

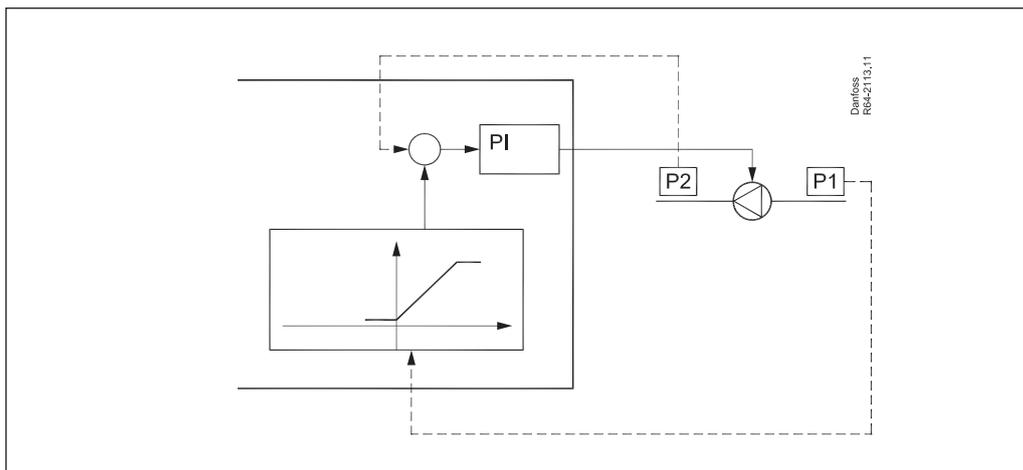|	
Show on overview	No
Quick settings	Heat + Amb. ...
PI name	General PI 1
Control mode	OFF
Control type	PI
External DI ctrl.	No
Input type select	Temperature
Input ref. select	Temperature
Reference	19.7
Ref. input	-200.0
Output type select	Voltage
Ref. X1	-20.0
Ref. Y1	55.0
Ref. X2	20.0
Ref. Y2	20.0
Alarm mode	OFF
Show advanced sett...	No
Kp	-5.0
Tn	60 s
Ref. filter time	10 s
Max. error	20.0
Min. control output	0 %
Max. control output	100 %
Startup time	10 s
Startup output	0 %
Stop output	0 %

Settings

Input select is "Temperature"
This is the Tsupply sensor.

Input ref select is "Temperature"
This is the Tamp sensor.

The reference is given by the line:
X_1, Y_1 = -20.0 , 55.0 and
X_2, Y_2 = 20.0 , 20.0

Notice that the Kp is negative for a "heat controller". We want the output to decrease when we're above the setpoint.

Pump control, delta P

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- Control a pump to deliver a fixed differential pressure.
- 2 pressure transmitters measure the pressure before and after the pump. P1 (before the pump) defines the reference for P2, by a line that is 1.2 (diff pressure) higher than P1.
- The pump must be speed controlled.
- Flow switch

Show on overview	No
Quick settings	Pump delta P
PI name	General PI 1
Control mode	OFF
Control type	PI
External DI ctrl.	Yes
Input type select	Pressure
Input ref. select	Pressure
Reference	1.3
Ref. input	-1.0
Output type select	Voltage
Ref. X1	0.0
Ref. Y1	1.2
Ref. X2	10.0
Ref. Y2	11.2
Alarm mode	OFF
Show advanced sett...	No
Kp	-5.0
Tn	30 s
Ref. filter time	2 s
Max. error	20.0
Min. control output	0 %
Max. control output	100 %
Startup time	15 s
Startup output	20 %
Stop output	0 %

Settings

Both "Input type" and "Input ref select" is set to pressure.

P2 (leaving pressure) is connected to the input. The supply pressure is connected to the reference input.

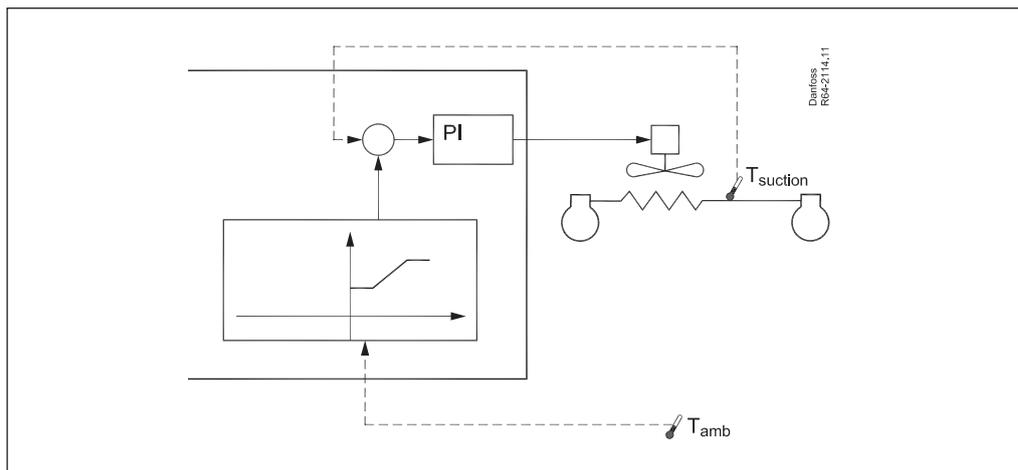The reference is given by the line:
$X_1, Y_1 = 0.0 , 1.2$ and
$X_2, Y_2 = 10.0 , 11.2$

The pump speed should decrease for increasing pressure, This gives a negative Kp.

The pressure will normally have a rather small time constant. Tn 20 - 60 sec.

De-superheater (booster)

- In a booster system the effency can be improved by cooling the low temperature discharge line.
- A coil with a fan (EC motor) will cool the discharge gas.
- The setpoint is set according to the ambient temperature.
- A minimum temperature is set to 20°C.

Show on overview	No
Quick settings	De-superheat
PI name	General PI 1
Control mode	OFF
Control type	PI
External DI ctrl.	Yes
Input type select	Temperature
Input ref. select	Temperature
Reference	50.7
Ref. input	-200.0
Output type select	Voltage
Ref. X1	20.0
Ref. Y1	25.0
Ref. X2	40.0
Ref. Y2	45.0
Alarm mode	OFF
Show advanced sett...	No
Kp	5.0
Tn	30 s
Ref. filter time	60 s
Max. error	20.0
Min. control output	0 %
Max. control output	100 %
Startup time	10 s
Startup output	50 %
Stop output	0 %

Settings

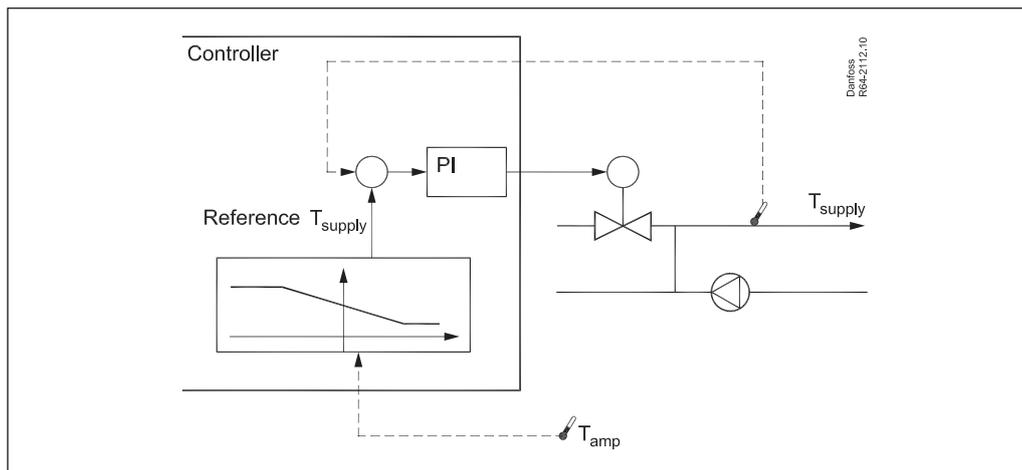Input select is "Temperature"
This is the Tsuction sensor.

Input ref select is "Temperature"
This is the Tamp sensor.

The reference is given by the line:
$X_1, Y_1 = 20.0 , 25.0$ and
$X_2, Y_2 = 40.0 , 45.0$

Notice that the Kp is positive. We want the output to increase when we're above the setpoint.

Floor heat

- This application is identical to "Heating with ambient compensation".

Show on overview	No
Quick settings	Floor heat
PI name	General PI 1
Control mode	OFF
Control type	PI
External DI ctrl.	No
Input type select	Temperature
Input ref. select	Temperature
Reference	30.0
Ref. input	-200.0
Output type select	PWM
Ref. X1	-20.0
Ref. Y1	30.0
Ref. X2	17.0
Ref. Y2	20.0
Alarm mode	OFF
PWM period time	6 s
Show advanced sett...	No
Kp	-5.0
Tn	1600 s
Ref. filter time	1 s
Max. error	20.0
Min. control output	0 %
Max. control output	100 %
Startup time	10 s
Startup output	0 %
Stop output	0 %

Drycooler + 3 way valve

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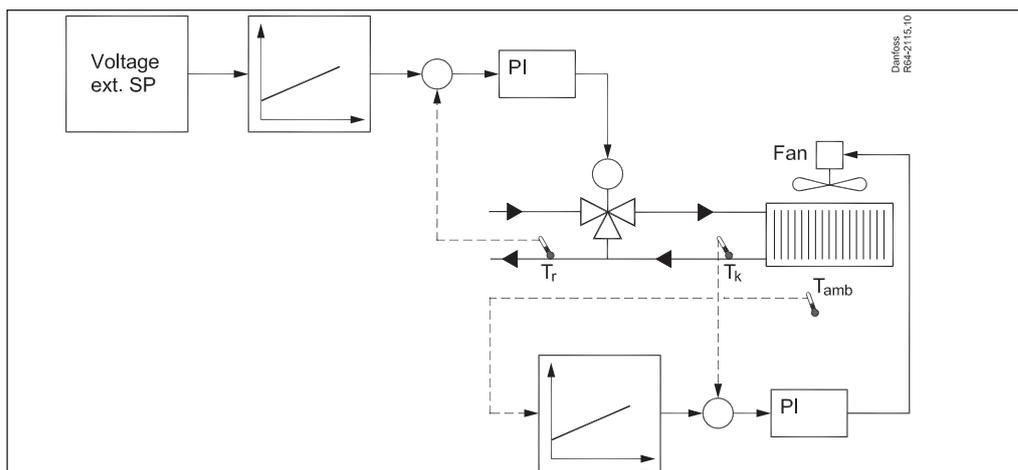
- Control a drycooler and the 3 way valve.
- A typical drycooler setup includes a drycooler and a 3 way valve for bypassing.
- The return temperature (Tr) is controlled by the 3 way valve. The setpoint for Tr is often adjustable. In this case we use a 0-10 V signal to give the setpoint for Tr.
- The drycooler fan are controlled by a PI controller measuring the leaving temperature (Tk). The Tk setpoint are floating with the ambient temperature.

3 way valve

Show on overview	No
Quick settings	Dry cool 3WV
PI name	General PI 1
Control mode	OFF
Control type	PI
External DI ctrl.	No
Input type select	Temperature
Input ref. select	Voltage
Reference	10.1
Ref. input	0.0
Output type select	Voltage
Ref. X1	0.0
Ref. Y1	10.0
Ref. X2	10.0
Ref. Y2	30.0
Alarm mode	OFF
Show advanced sett...	Yes
Kp	-5.0
Tn	100 s
Ref. filter time	120 s
Max. error	20.0
Min. control output	0 %
Max. control output	100 %
Startup time	10 s
Startup output	50 %
Stop output	0 %

Fan

Show on overview	No
Quick settings	Dry cool fan
PI name	General PI 1
Control mode	OFF
Control type	PI
External DI ctrl.	No
Input type select	Temperature
Input ref. select	Temperature
Reference	10.3
Ref. input	-200.0
Output type select	Voltage
Ref. X1	10.0
Ref. Y1	14.0
Ref. X2	30.0
Ref. Y2	34.0
Alarm mode	OFF
Show advanced sett...	Yes
Kp	5.0
Tn	60 s
Ref. filter time	120 s
Max. error	20.0
Min. control output	0 %
Max. control output	100 %
Startup time	10 s
Startup output	0 %
Stop output	0 %

← Press "Yes" to see all the settings

Simple superheat controller

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R64-2116,10

S₂ — S_2

P

PI

EEV
Evaporator
AKV/ETS/CCMT
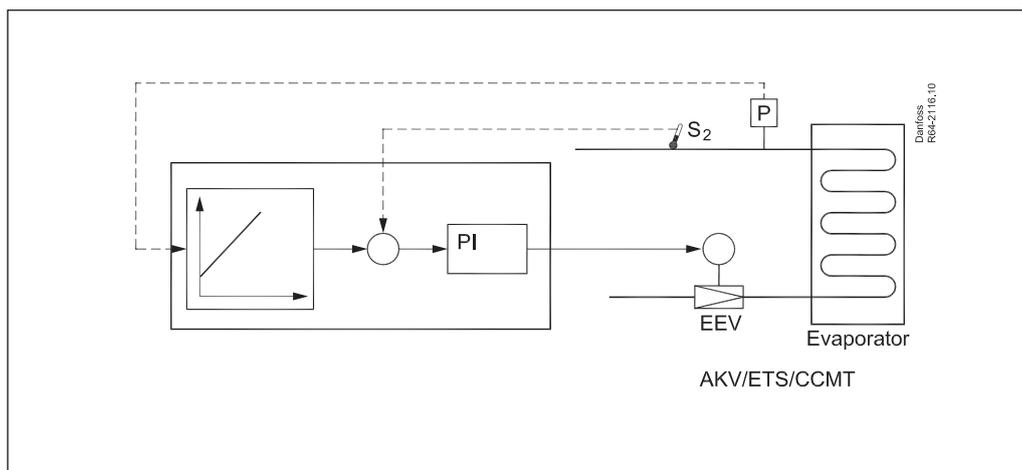
- Control an electronic expansion valve.
- The saturated temperature is taken from a saturated temperature (Press to temp, To-MT, To-LT, Trec etc)
- From this temperature the reference for the S2 sensor is calculated via the (X1,Y1) and (X2,Y2) curve. The S2 reference should be 10 K higher than the saturated temperature (superheat). If a lower SH is wanted change the values Y1 and Y2.

A simple superheat controller for ETS, AKV.

Do not expect optimal superheat control.

Normally you need a dedicated controller for superheat control, However it's possible to make a simple controller that controls similar to a TXV with a steppermotor valve or an AKV valve.

Limitations
You can only use the refrigerant selected for the controller in "Plant setup"

Show on overview	No
Quick settings	SH control
PI name	General PI 1
Control mode	OFF
Control type	PI
External DI ctrl.	Yes
→ Input type select	Temperature
→ Input ref. select	Press to temp
Reference	8.7
Ref. input	-1.3
Output type select	Stepper
Ref. X1	-50.0
Ref. Y1	-40.0
Ref. X2	50.0
Ref. Y2	60.0
Alarm mode	OFF
Show advanced sett...	Yes
Kp	5.0
Tn	120 s
Ref. filter time	3 s
Max. error	10.0
Min. control output	0 %
Max. control output	100 %
Startup time	10 s
Startup output	30 %
Stop output	0 %

Settings

Input select type is "Press to temp" for the Po input and input ref select is set to "Temperature" for the S2 sensor.

Also note the setting of "Startup output" (0)

Signal converter
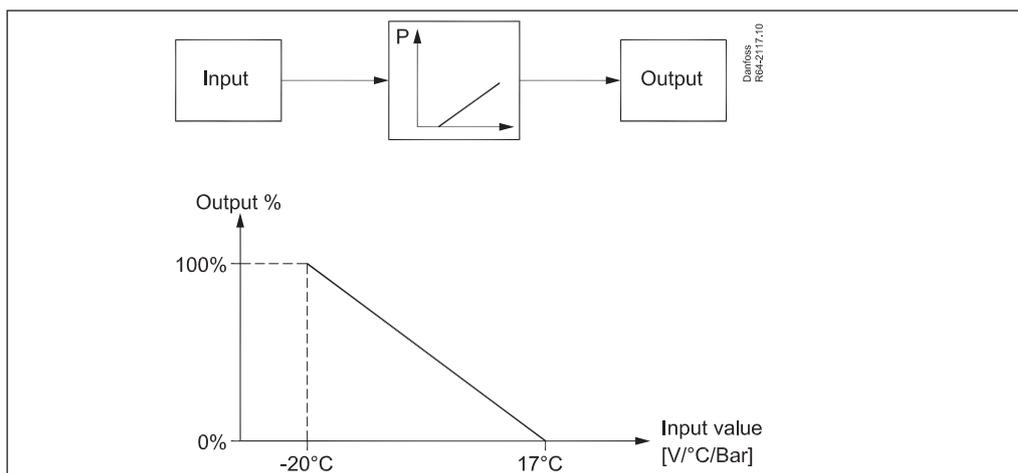
- Convert one signal to a different signal fx
  - A voltage signal to a different voltage signal
  - A temperature to a voltage signal
- The voltage converters can also convert voltage signals into stepper motor positions or AKV opening degrees (PWM).
- Setting the general PI controller into the "Proportional" control mode (P) it will act as a signal converter that can convert an input signal to a different output signal.

1. Set the controller into "P" (proportional mode).
2. Select the input type (voltage/ temperature / pressure etc)
3. Select "Fixed ref" as "input ref select"
4. Set the "Output type select" to the wanted output (PWM/Stepper/Voltage).
5. Set the Kp to the slope. How many % output change pr input unit – with sign! If the output is decreasing for increasing input the sign is negative!
6. Set the "Setpoint" to the lowest input value .
7. If the Kp is positive then set "Startup output" to 0%.
    If Kp is negative then set "Startup output" to 100%
8. Set the "Min control output" to the minimum output %
9. Set the "Max control output" to the maximum output %
10. Set Startup time to 1 s.

0 - 5 V to PWM

Show on overview	No
Quick settings	Convert 0-5V
PI name	General PI 1
Control mode	OFF
Control type	P
External DI ctrl.	No
Input type select	Voltage
Input ref. select	Fixed ref.
Setpoint	0.0
Reference	-35.6
Output type select	PWM
Alarm mode	OFF
PWM period time	6 s
Show advanced sett...	No
Kp	20.0
Ref. filter time	60 s
Max. error	100.0
Min. control output	0 %
Max. control output	100 %
Startup time	1 s
Startup output	0 %
Stop output	0 %

5 - 10 V to PWM

Show on overview	No
Quick settings	Convert 5-10V
PI name	General PI 1
Control mode	OFF
Control type	P
External DI ctrl.	No
Input type select	Voltage
Input ref. select	Fixed ref.
Setpoint	5.0
Reference	-16.3
Output type select	PWM
Alarm mode	OFF
PWM period time	6 s
Show advanced sett...	No
Kp	2.7
Ref. filter time	60 s
Max. error	100.0
Min. control output	0 %
Max. control output	100 %
Startup time	1 s
Startup output	0 %
Stop output	0 %

Temperature to voltage

Show on overview	No
Quick settings	Temp. to volt
PI name	General PI 1
Control mode	OFF
Control type	P
External DI ctrl.	No
Input type select	Temperature
Input ref. select	Fixed ref.
Setpoint	-17.0
Reference	-12.6
Output type select	Voltage
Alarm mode	OFF
Show advanced sett...	No
Kp	10.0
Ref. filter time	60 s
Max. error	100.0
Min. control output	0 %
Max. control output	100 %
Startup time	1 s
Startup output	100 %
Stop output	0 %

In this example -20°C will give 10 V output (100%) and +17°C will give 0 V (0%)
The reference is set to -20°C.
The Kp is calculated to
(0%-100%) / (17°C - (-20°C)) = -100/37 = -2.7 (note negative).

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