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Article

District heating house substations **and selection of regulating valves**

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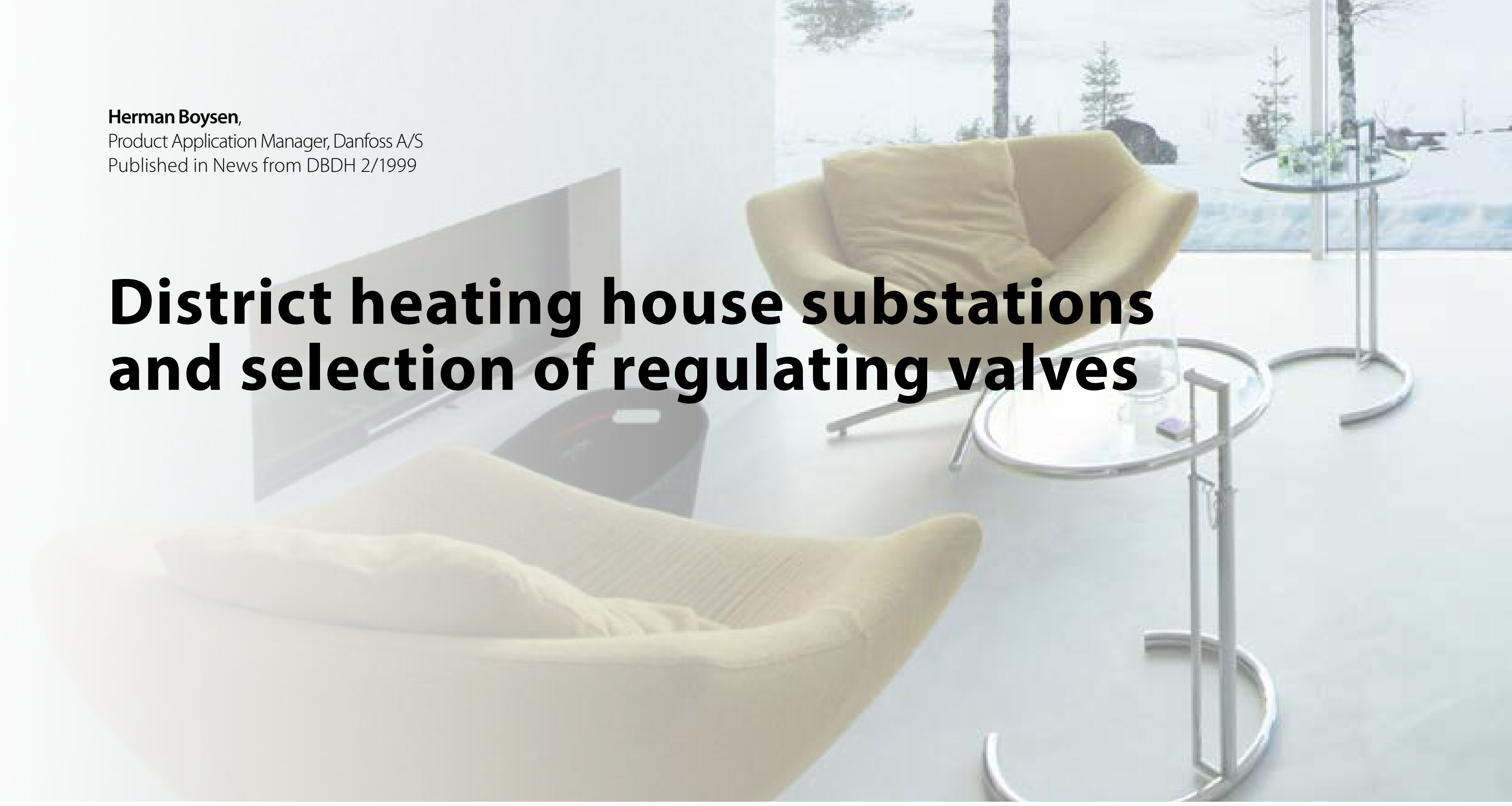


District heating house substations and selection of regulating valves

1. Introduction

The precondition for well – operating district heating house substations is the optimum choice of correct control components for the substations, and that they are used according to purpose. Thus correct use of the components ensures optimum function.

Optimum function provides:

- Low energy consumption
- Large degree of cooling of the district heating water
- High degree of comfort
- Minimum operational breakdowns
- Long life
- Minimum maintenance

Correctly chosen components are components with properties that meet the stated specifications concerning pressure and temperatures of the supply network, as well as control valves that are sized correctly. Furthermore, it is a requirement that the substations are adjusted according to actual consumption and system conditions such as pressure and temperatures.

Conditions that are particularly important in order to achieve a good result are mentioned below. Each of the mentioned conditions will be explained later in this article.

1. Control ratio of the control valve
2. Valve authority
3. Control accuracy
4. Differential pressure control
5. Adjustment

2. Control ratio

The control ratio of a control valve expresses how regular the control characteristic of the valve is. The text below explains that the higher a control ratio of a control valve, the better the control capability of the valve.

The German recommendation VDI/VDE 2173 states the rules of defining the control ratio of a valve. The control ratio is here defined as the relationship between the k_{vs} and the k_{vr} value of the valve.

$$R = \frac{k_{vs}}{k_{vr}}$$

k_{vs} is the max. capacity of a control valve, m^3/h. The valve capacity is based on a pre – calculated capacity demand, $k_v = Q/ÖDP_v$. Q is the calculated flow of district heating water through the control valve in m^3/h, and DP_v is the differential pressure across the control valve in bar.

k_{vr} is the lowest capacity of the valve at which the control characteristic is regular. Control of domestic hot water temperatures in heat exchanger systems with opening degrees of the valve below the values which corresponds with k_{vr} might cause hunting in the domestic hot – water temperature.

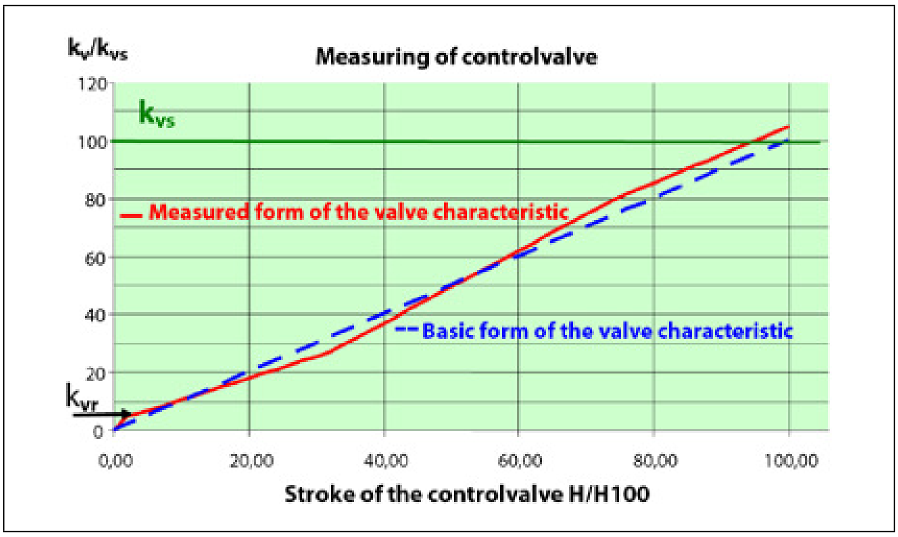


FIGURE 1: Example of a measurement of the k_{vr} value of a valve with a linear valve characteristic

A lift that corresponds with the k_{vr} is normally the lowest degree of opening at which a stable control can be expected.

The recommendation defines k_{vr} the following way:

If a measured control characteristic of a control valve is compared with the basic characteristic of the valve characteristic type in question, there will often be a deviation between the basic characteristic and the measured valve characteristic.

The deviation from the ideal characteristic will often be larger in the lower part of the control characteristic of the valve.

The value of the k_{vr} valve in the ideal characteristic is determined between 0 and 10 % of the valve stroke on the spot where the gradient of the actual valve characteristic deviates more than 30 % from the basic form of the characteristic (cf. fig. 1).

For district heating control linear valve characteristics are normally used in connection with self-acting valves or differential pressure control and thermostatic temperature control.

For motorized valves for temperature control, either exponential characteristics or another form of adjusted valve characteristics are used.

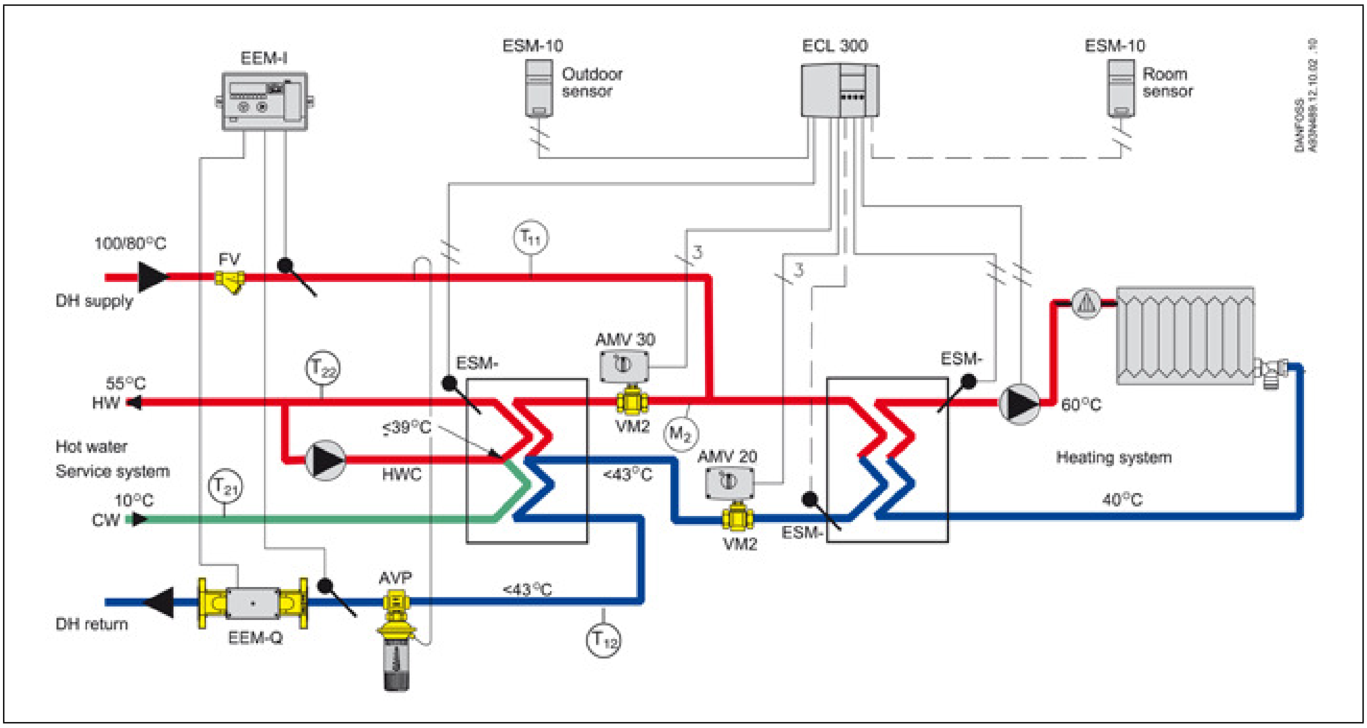


FIGURE 2: Two – step house substation with one radiator circuit and one domestic hot – water circuit

Flow calculation – district heating system (DH)		
Shower flow rate and heating performance – one tapping		
Normal shower flow rate, QSH		12 l/min. (0.2 l/sec)
Shower temperature, TSH		41 °C
Cold water temperature, T21		10 °C
Cold water heated from 10 °C to 41 °C for a shower		31 °C
Performance, one tapping, PHW	= 0.2×3600×(41-10)×1.16/100	25.9 kW (22.7 Mcal)
Hot-water flow rate – district heating		
Hot water temperature, T_{22}		55 °C
Cold water temperature, T_{21}		10 °C
Shower flow rate, QHW	= 25.9×1000/(55-10)/1.16/3600	0.14 l/sec
District heating flow rate – one tapping		
Temperature increasing ΔT in the second step of the heat exchanger system:		
According to table	ΔT ~ 39 - 55 °C,	16 °C
District heating performance, PDH1	= 0.14×3600×(55-39)×1.16/1000	9.35 kW (8.04 Mcal/h)
District heating supply temperature, T_{11} (winter time)		100 °C
District heating return temperature (second step), T_{12}		43 °C
District heating flow rate, QDH_{min}	= 9.35×1000/(100-43)/1.16/3600	0.039 l/sec (0.14 m^3/h)

Table 1

Valves with a linear control ratio typically have a high control ratio, R = 50 – 200, whereas the typical control ratio of exponential and logarithmic valves is R = 30 – 50.

Control ratio for district heating control

The requirements for the control ratio is particularly critical in domestic hot– –water systems in which the primary flow varies much according to the consumption of hot – water. It is required that the domestic hot – water temperature is stable under varying consumption.

To meet these specifications, experience has taught us that this places heavy demands on the control equipment and not at least on the control ratio of the motorized valves.

As a stable control at flow quantities of k_v values < k_{vr} cannot to be expected, as already mentioned, it is necessary to ensure that the valve operates with lifts between k_{vr} and k_{vs}.

In large – sized domestic hot – water systems a relevant requirement could be that the system is capable of controlling a flow quantity down to a quantity which amounts to the hotwater supply when only one person takes a shower in the system.

To meet this requirement, the motorized valve is to be chosen so that it is capable of controlling at an opening degree of $k_v > k_{vr}$ when only one person takes a shower in the system. k_{vr} is calculated by means of the stated R and k_{vs} data of the control valve, $k_{vr} = k_{vs}/R$.

Further information about control requirements will follow later in this article.

The most critical domestic hotwater systems for district heating systems are the two – step systems in connection with direct heat exchange, cf. fig. 2.

Looking at a two – step system we see that the return water of the radiator circuit pre – heats the domestic cold water in the hot water heat exchanger.

The task for the motorized valves is to after heat the hot water in the heat exchanger. The lowest capacity of this motorized valve in the hot water system is, when the radiator circuit is at max. load. Then the normal temperature of the domestic hot – water temperature after preheating will often reach 35 – 39 °C. Consequently, only a limited quantity of additional district heating water will be required to reach the tapping temperature of app. 55 °C.

The most critical circumstances under which the motorized valve must work in the hot – water circuit without hunting exist when the hot – water consumption is low and return temperature from the heating system is high.This often happens during winter time when the load on the heating system is high.

Under this conditions the motorized valve operates with a low degree of opening.

A calculation of the min. capacity of a motorized valve for domestic hotwater heating can be based on the following considerations:

Fig. 2 states some of the typical temperature conditions of a two – step district heating house substation.

Tables 1 and 2 calculate a motorized valve for at system with a performance of 300 kW. Furthermore, table 3 calculates the requirements for this valve which will be necessary to handle a stable control at a flow that corresponds with the amount of water needed for a shower.

The calculation is based on the min. recommended available differential pressure in the system = 0.1 mPa (1 bar) and $\Delta P_{v100} = 0.5$ bar across the motorized valve. The available differential pressure will often be higher than the base for calculating valves.

Valve capacity: Heat exchanger capacity 300 kW		
ΔPDH supply		1.0 bar
ΔP_v, ΔP across the valve, basis of valve sizing		0.5 bar
Performance		300 kW (258 Mcal/h)
DH supply temperature (summer time) T_{11}		65 °C
DH return temperature T_{12}		25 °C
DH flow rate, Q_{max}	= 300×1000/(65-25)/1.16/3600	1.8 l/sec (6.4 m^3/h)
Valve capacity, k_v	= Qmax/√ΔPv; kv = 6.4/√0.50	9.05 m^3/h
Valve choice		VF2, DN 25, k_{vs} = 10 m^3/h

Table 2

Control ratio		
Primary flow, one tapping:		
Tapping of the shower		0.14 m^3/h
Hot water circulation		0.06 m^3/h
Total		0.20 m^3/h
$\Delta P_{v\,min}$ at one tapping (without ΔP controller) (ΔP_v ~ system ΔP)		≅ 1.0 bar
Valve capacity, k_{vmin}	$k_{vmin} = QDH_{min}/\sqrt{\Delta P_{v\,min}} = 0.20/\sqrt{1}$	0.20 m^3/h
ΔP = 1 bar (100 kPa)		
Control ratio R = k_{vs}/k_{vmin}	= 10.0/0.20	~ 50 (1:50)
$\Delta P_{v\,min}$	~ 3.0 bar (300 kPa)	
Valve capacity	$k_{vmin} = QDH_{min}/\sqrt{\Delta P_{v\,min}} = 0.20/\sqrt{3.0}$	0.12 m^3/h
Control ratio R = k_{vs}/k_{vmin}	= 10.0/0.12	~ 86 (1:86)

Table 3

Furthermore, the calculations show how the requirement for the control ratio becomes more stringent if the differential pressure ΔP in the example is increased to 3 bar. In this calculation example the system is not equipped with a differential pressure controller.

The calculation includes the consumption for the circulation of the domestic hot water. The calculation is based on a circulating hot – water flow of 10 % of the max. flow and a cooling of 5 °C of the circulated amount of water.

Fig. 3 illustrates the requirements for the control ratio as function of the differential pressure and different capacities in a domestic hot – water system, with and without a differential pressure controller. The figure shows that a valve – in compliance with the stated requirements for stable control – is capable of controlling heat exchangers with a control ratio of R = 50 at capacities up to 300 kW and down to a capacity that would correspond with one shower without any risk of hunting.

Systems without differential pressure controllers.

According to fig. 3, the requirement as to the k_{vr} value on control valve increases at increased capacity and at increased differential pressure ΔP across the system if differential pressure controllers are not applied in the system. An example: From the table 3 we saw that the requirement as to control ratio would be R = 86 if the differential pressure ΔP is increased to 3 bar.

Systems with differential pressure controllers.

If differential pressure controllers are used, they will ensure a constant differential pressure across the control valve regardless of differential pressure variations in the network.

The requirements for the k_{vr} of the control valve will not change according to the varying differential pressure of the system. In practice experience has shown that differential pressure controllers have a stabilizing effect on temperature control if differential pressures in a district heating system are high and vary.

2. Valve authority

The valve authority Va expresses the authority the valve has in the system circuit in which it is chosen to control. Va is expressed by the relationship between the differential pressure across the control valve at 100 % load (i.e. open valve) ΔP_{v100} and the differential pressure across the control valve when it is fully closed (no consumption in the system) ΔP_{v0}.

$Va = \Delta P_{v100}/\Delta P_{v0}$ ($\Delta P_{vmin}/\Delta P_{vmax}$)

The valve authority is normally expressed as a percentage.

One of the requirements that are often used in connection with the choice of control valves is to choose them with a valve authority of min. 50 %, i.e. at least 50 % of the differential pressure across the systems is throttled away in the control valves.

$Va = \Delta P_{v100}/\Delta P_{v0} \times 100 \geq 50\%$

The better the authority of valve is, the better the flow is controlled according to the control characteristic.

At a small valve authority the differential pressure across the control valve ΔP_v will fall heavily at increased degree of opening. Consequently, the flow variation at small lifts will be large whereas it will be small at large lifts. This will result in a large power gain and a risk of unstable control at small lifts whereas the power gain will be small at large lifts of the valve which would result in a large control deviation.

System without differential pressure controller.

In systems without a differential pressure controller, the differential pressure across the control valve in closed condition (ΔP_{v0}) = the differential pressure of the entire system. The differential pressure of the system can also be calculated as the total sum of the pressure drops across all components in the substation which could be heat meter (ΔP_{hm}) heat exchanger (ΔP_{he}) and other individual resistances (ΔP_{pipe}) and with a fully open control valve (ΔP_{v100}). Consequently, the valve authority will be:

$$Va = [\Delta P_{v100}/(\Delta P_{v100} + \Delta P_{hm} + \Delta P_{str} + \Delta P_{he} + \Delta P_{pipe})] \times 100\ (\%).$$

System with differential pressure controller.

In systems with a differential pressure controller, the differential pressure across the control valve in closed condition = the set value of the differential pressure controller ($\Delta P_{v100} + \Delta P_{he}$). The differential pressure across the control valve at max. load (100 %) will be the set value of the differential controller ÷ the pressure drop across the heat exchanger ($\Delta P_{set} - \Delta P_{he}$).

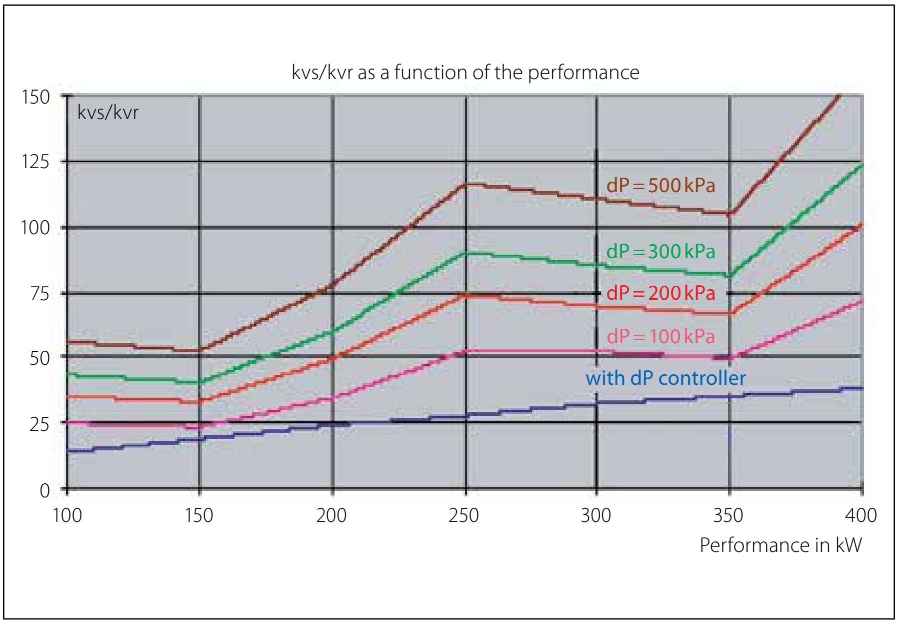


FIGURE 3: Requirement R=k_{vs}/k_{vr} for control valves as a function of the performance and the system DP

$$Va = \frac{\Delta P_{set} - \Delta P_{he}}{\Delta P_{set}} \times 100\%$$

or

$$Va = \frac{\Delta P_{v100}}{(\Delta P_{v100} + \Delta P_{he})} \times 100\%$$

3. Control accuracy

District heating house substations often comprise a domestic hot – water circuit and a radiator circuit.

Normally the radiator circuit is controlled by weather compensation equipment, and as the load variation is limited in a 24 – hour period and load variations are slow, the control of these systems is rather uncritical. Furthermore, there will be a certain degree of pre – compensation from the district heating works by means of a weather compensated flow temperature.

The domestic hot – water circuit is controlled differently. The load variations are momentary and large. This type of load makes heavy demands on the control equipment's capability to control the temperature of the domestic hot water accurately.

Frequently used requirements for control accuracy as to control equipment for domestic hot – water control in district heating systems are

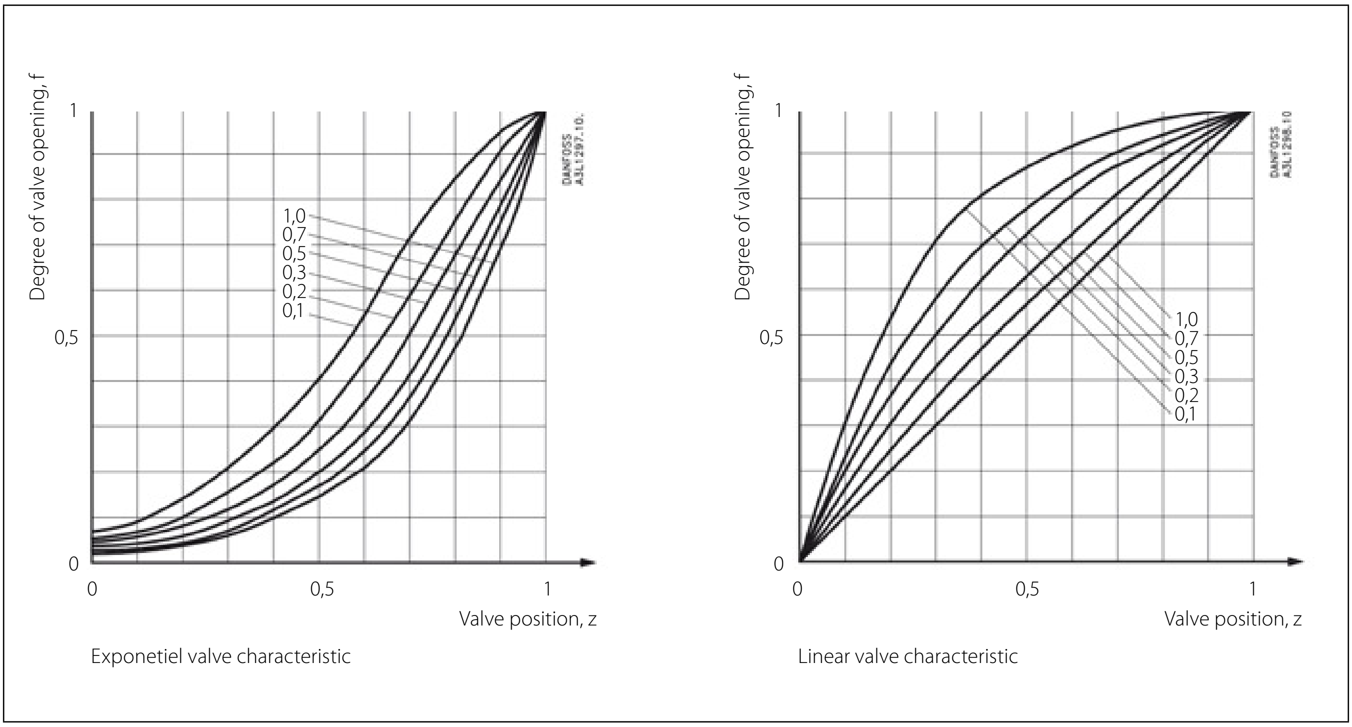


FIGURE 4: Effective valve characteristics with authority range 0.1 to 1.0 (10 % to 100 %)

the recommendations for control of domestic hot – water systems issued by the Finnish District Heating Association, cf. fig. 5.

Experience shows that it is often difficult to comply with these requirements.

The cause of the problems will often be:

- Oversized control valves.
- Too large variations in the differential pressures in the system.
- Too poor a quality of the control valves.
- Incorrect settings of the controllers.
- Incorrect sensor placing.

Based on laboratory tests and simulation of the operation of the systems in question, following pieces of advice can be offered for the choice of control equipment for domestic hot – water circuits:

- Choose motorized valves with a short running time, max. 20 – 25 seconds from a fully closed valve to a fully opened valve.
- The time constant of the sensor must be ≤ 3 seconds, and the sensor must be placed as near to the heat exchanger as possible.
- Observe that the required control ratio is met. This can partly be achieved by choosing the correct valves and partly by adjusting the systems correctly, topics that will be described below.
- Adjust the systems to operate at fully opened valves at 100 % load, cf. the instructions later in this article.
- Choose valves with sufficient system authority. The authority is especially critical in systems with a low differential pressure.
- Avoid large pressure variations in the systems by applying differential pressure controllers. Differential pressure controllers also have a positive effect on the control capability of the valve. More detailed information later in this article.

4. Differential pressure control

If differential pressure controllers are used in a subscriber station, a constant differential pressure across the substation can be obtained regardless of variations in network pressure. This offers the control valves improved control conditions.

End – user advantages:

- Simple adjustment of the subscriber station.
- Stabilization of the temperature control.
- Low noise level in the system.
- Prolonged life of the control equipment.

Producer advantages:

- Good distribution of water in the supply network.
- Delimitation of the circulating water quantity in the network.

Use of differential pressure controllers will ensure that the valve operates at the highest possible degree of opening and thus that the valve operates with lifts that correspond with the k_v values > k_{vr}.

A correct choice of products and correctly sized valves as well as adjustment for the optimum operation is the precondition that a subscriber station operates well. Choose valves with control ratio that will ensure a stable control and sufficient valve authority.

The application of differential controllers in a subscriber station is the most important step to comply with the above – mentioned preconditions. In other words, the differential controller ensures that the differential pressure, which is the basis for the sizing of valves, is maintained. This again is an important precondition of stable temperature control.

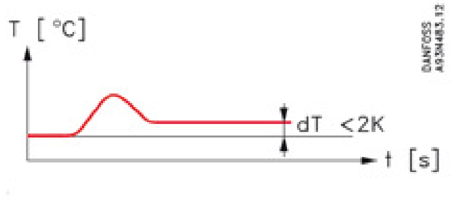
5. Adjustment

Adjustment of a subscriber station ensures the highest possible degree of opening at 100 % load.

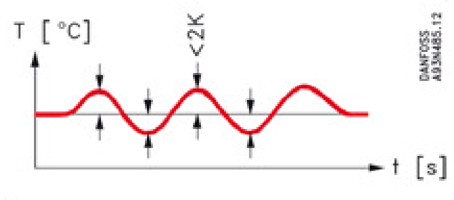
This is the prior condition to gain full effect of the control ratio of the valve as the control ratio is calculated on the basis of the kvs value of the control valve.

Normally valves are sized by calculating the k_v value on the basis of the flow through the valve and a selected pressure drop across the valve considering the valve authority ($k_v = Q/\sqrt{\Delta P_v}$ m³/h). Based on the

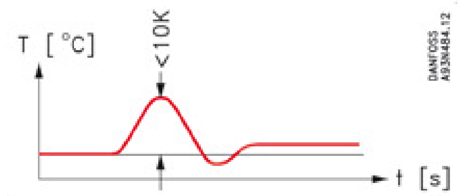
Constant permanent deviation from set point after a temperature change, +/- 2 K



Maximum permanent temperature oscillations, +/- 2 K



Maximum temperature deviation after a momentary load change, 10 K



Transient time after a load change <+/- 2 K within 120 sec

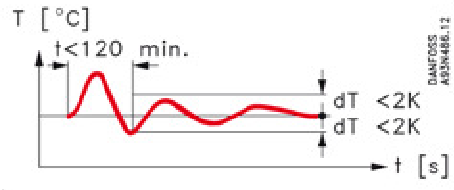


FIGURE 5: The specification of the Finnish District Heating Association concerns requirements for control accuracy of the domestic hot-water temperature – requirements, which often are used wholly or partly in connection with the preparation of technical specifications for tenders

calculated k_v value, a valve with a suitable k_{vs} value is chosen, i.e. with a value which is often a bit higher than the calculated value. The adjustment procedure is then to set the differential pressure controller at a lower differential pressure so that the control valves are fully open at 100% load. As it is often difficult to simulate a situation at 100% load, the setting pressure ΔP can be calculated by means of the k_v formula $\Delta P = (Q/k_{vs})\,2$ bar.

Conclusion

As the article states, a perfect control result considers the valve control ratio as well as a good valve authority of the control valve during the entire load cycle. Furthermore, it is important that the district heating house substation is adjusted before normal operation.

Control ratio

The control ratio of district heating valves in the market lies between R = 30 – 50. Based on these values, it is possible to calculate the lowest performance at which a stable control can be expected. However, prior conditions are stable operation in the supply network and at the level on which the sizing was based. As this is rarely the case, the use of differential pressure controllers is recommended.

Valve authority

Contrary to the effect of the control ratio, the valve authority will increase at increasing differential pressure in the district heating network and thus have a positive influence on the control stability. In house substations without differential pressure controllers, increased differential pressure in the network will as a result be placed on the control valve. As the differential pressure of the network normally is higher than the pressure the sizing was based on, problems with the valve authority in the house substations will generally not exist.

In systems with a low differential system pressure, differential pressure controllers will ensure a good valve authority and consequently, a stable control.

Adjustment

As the article states, the adjustment of the district heating house substation is an important precondition for the optimum operation of control valves.

Use of differential pressure controllers in district heating stations offers the following advantages:

- Unchanged requirements as to control ratio of the control valve at increased differential pressure in the network.
- A good valve authority across the control valve is preserved even at low differential pressure in the network.
- Adjustment of the house substations will be simplified to a high extent. The operation of the district heating station remains the same even at large variations such as load and differential pressure in the district heating network.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