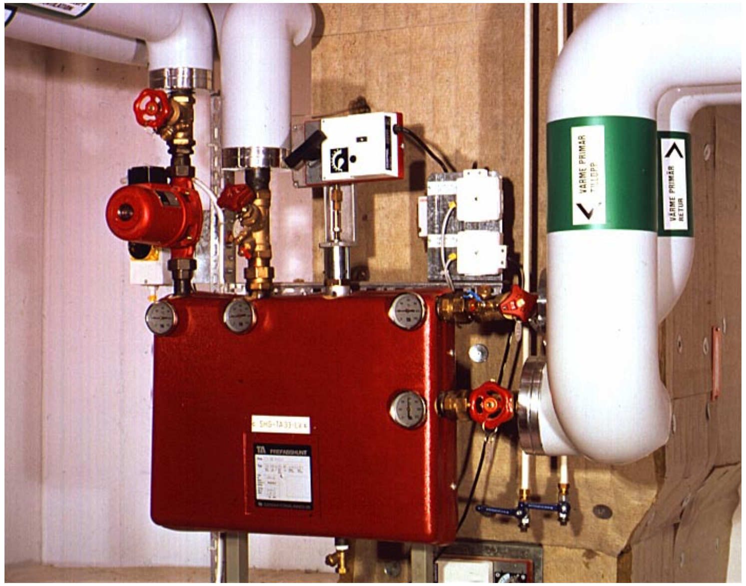

BALANCING OF CONTROL LOOPS

A manual for getting the correct function of 23 control loops used in hydronic heating and cooling systems.

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Casselden Place, Melbourne, Australia

Balancing of Control Loops is No. 1 in the Tour & Andersson series of publications for HVAC practitioners. Manual No. 2 deals with balancing distribution systems. Manual No. 3 deals with balancing radiator systems and manual No 4 deals with Stabilising differential pressure.

Please note that this publication has been prepared for an international audience. Since the use of language differs somewhat from country to country, you may find that some of the terms and symbols are not the same as those you are used to. We hope this does not cause too much inconvenience.

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Production: Tour & Andersson AB, Technical Documentation
— second version —

Contents

1. Why balance?

Many property managers spend fortunes dealing with complaints about the indoor climate. This may be the case even in new buildings using the most recent control technology. These problems are widespread:

- Some rooms never reach the desired temperatures, particularly after load changes.
- Room temperatures keep swinging, particularly at low and medium loads, even though the terminals have sophisticated controllers.
- Although the rated power of the production units may be sufficient, design power can't be transmitted, particularly during startup after weekend or night set back.

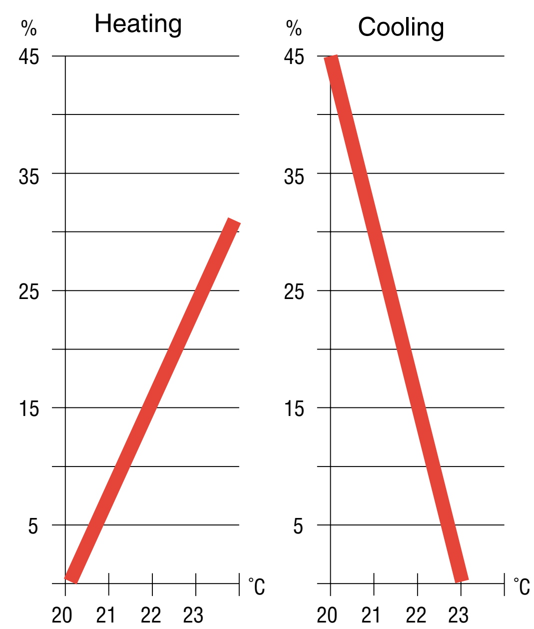
These problems frequently occur because incorrect flows keep controllers from doing their job. Controllers can control efficiently only if design flows prevail in the plant when operating under design conditions.
The only way to get design flows is to balance the plant. Balancing means adjusting the flow by means of balancing valves. This has to be done in three respects:

1. The production units must be balanced to obtain design flow in each boiler or chiller. Furthermore in most cases, the flow in each unit has to be kept constant. Fluctuations reduce the production efficiency, shorten the life of the production units and make effective control difficult.

2. The distribution system must be balanced to make sure all terminals can receive at least design flow, regardless of the total load on the plant.

3. The control loops must be balanced to bring about the proper working conditions for the control valves and to make primary and secondary flows compatible.
   This manual deals with the balancing of control loops. It tells you how to balance 23 common control loops using two-way and three-way control valves.
   For manual about the balancing of distribution systems, please see TA manual No. 2.
   Manual 3 concerns Balancing of radiator systems while manual 4 examines the stabilisation of the differential pressure.

Percentage increase in energy costs for every degree C too high, or too low, relative to average building temperature.



Why is the average temperature higher in a plant not balanced? During cold weather it would be too hot close to the boiler and too cold on the top floors. People would increase the supply temperature in the building. People on the top floors would stop complaining and people close to the boiler would open the windows. During hot weather the same applies. It is just that it would be too cold close to the chiller, and too hot on the top floors.

One degree more or less in a single room rarely makes any difference to human comfort or to energy costs. But when the average temperature in the building is wrong, it becomes costly.

One degree above 20 degrees C increases heating costs by at least 8 percent in mid Europe (12% in the south of Europe). One degree below 23 degrees C increases cooling costs by 15 percent in Europe.

Three things are necessary:
Flow measuring and regulating devices, measurement instrument and a balancing procedure.

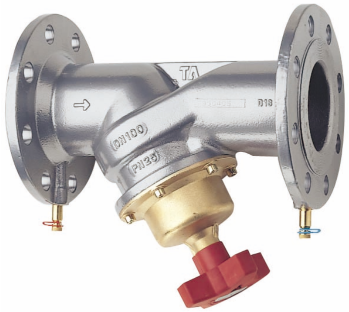
Flow measuring and regulating devices. These are
Balancing valves which are both variable orifice and regulating valves or Orifice devices with an independent regulating valve.

There is a great difference between balancing valves of different makes. This translates into an equally great difference in the accuracy of indoor climate control, in energy savings—and in the time, cost and effort required to do an adequate balancing job.

TA, whose products are used worldwide, cater for all the different market requirements and offer both fixed and variable flow measuring devices and regulating valves.

These are some of the distinguishing features of TA products:

STAD
STAD balancing valve
15 to 50 mm



STAF
STAF balancing valve
20 to 300 mm

STAP
STAP Differential pressure controller
15 to 50 mm

Balancing valves and **orifice devices**

- Flow precision for valves better than +/- 5% and for fixed orifices better than +/- 3%.
- Sizes up to 50 mm have four full turns from open to closed position. Larger sizes have eight, twelve or sixteen full turns.
- The valves are available with internal threads, with flanges, with welded or soldered valve ends, with grooved ends and with compression fittings.
- Sizes up to 50 mm are made of Ametal®, probably the only pressure die casting alloy that meets the world's toughest demands for resistance to dezincification.

Differential pressure controller
Adjustable set point: 10-60 kPa and 20-80 kPa.
To stabilize the differential pressure across the control valves and/or circuits.

Measurement instrument. Measuring is required in order to really know that design flows are achieved and also to find what differential pressures that are applied in different parts of the plant. It is also a good tool for trouble-shooting and system analyses.

The balancing instrument CBI^{II} from TA Hydronics has all necessary features to fulfil these demands, eg:

- Measures and documents differential pressure, flow and temperature of STAD, STAF, STAP/STAM and other valves from TA Hydronics.
- Programmed to calculate presetting values for balancing and also the TA Method and TA Balance.
- Two-way communication with PC.
- Corrects the calculations for antifreeze agents.
- Large storage capacity - can handle 1000 valves and 24 000 values when logging.
- Graphic display making it possible to assign plain-language names for plants and valves.

Proportional relief valve. In variable flow system, a TA BPV valve can be used to perform three distinct functions:

- ensure a minimum flow to protect the pump.
- reduce the temperature drop in pipes.
- limit the differential pressure on the terminal circuits.

The BPV has a shut-off function and preset point of 10–60 kPa.
15 to 32 mm (1/2" to 1 1/4")

3.1 Variable primary and secondary flows

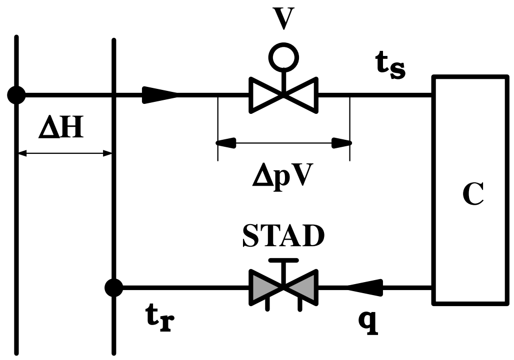


Fig. 1. Control of a variable flow terminal unit

In Fig 1 the two-way control valve controls the coil output by adapting the water flow.

The authority of the control valve ß' = ΔpcV /ΔH. The term "authority" is explained in detail in Appendix A and B.

The two-way control valve is selected to create, fully open and design flow, a pressure drop ΔpV = ΔH - ΔpC - 3 (kPa)

Moreover this value ΔpV must be higher than 0.25 x ΔHmax.

Balancing procedure fig 1

1. Open all control valves fully.
2. Adjust to design flow with STAD. Do this as part of the balancing procedure for the entire primary system (see TA manual No 2).

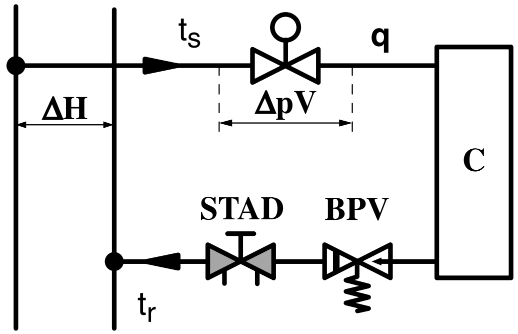


Fig. 2. A modulating relief valve reduces the differential pressure by a constant value regardless of the flow.

When the control valve is oversized, for instance due to the limited choice of Kv values, the primary differential pressure can be indirectly reduced by means of a BPV modulating relief valve. The BPV reduces the differential pressure by a constant value regardless of the flow.

The control valve authority ß' = ΔpcV / (ΔH - ΔpBPV).

Balancing procedure fig 2

1. Open all control valves fully. Make sure all the BPVs are open (minimum setpoint).
2. Adjust to design flow with STAD. Do this as part of the balancing procedure for the entire primary system (see TA manual No 2) and before you proceed to step 3.
3. Find out which handwheel setting of STAD that will create a pressure loss of at least 3 kPa in STAD for design flow. Use the CBI or a TA nomogram to find the correct setting.
4. Readjust STAD according to step 3. The flow in STAD should now be higher than design value.
5. Adjust the setpoint of the BPV until you get back to design flow in STAD. Measure the flow in STAD as you adjust the BPV.

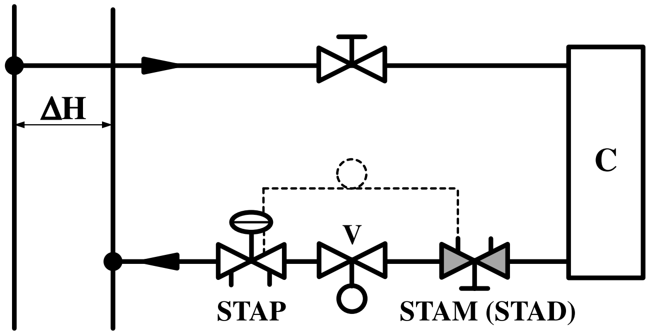


Fig. 3. A Δp controller keeps constant the differential pressure across the control valve.

Depending on the design of the plant, the differential pressure available on some circuits can vary dramatically with the load. In this case, to obtain and maintain the correct control valves characteristic, the differential pressure across the control valves can be maintained practically constant with a Δp controller as represented on figure 3.

The differential pressure across the control valve ”V” is detected on one side by connecting the capillary downstream the measuring valve STAM. The pressure on the other side is connected directly to the acting membrane by an internal connection in the STAP.

When the differential pressure across the control valve increases, the STAP closes proportionally to compensate.

The control valve ”V” is never oversized as the design flow is always obtained for the valve fully open and its authority is and remains close to one.

All additional differential pressure is applied to the STAP. The control of the differential pressure is quite easy in comparison with a temperature control and a sufficient proportional band can be used to avoid hunting.

As the flows are correct at each terminal, no other balancing procedure is required. If all control valves are combined with STAP, then balancing valves in branches and risers are not necessary but for diagnosis purposes.

Balancing procedure fig 3

1. Open fully the control valve ”V”.
2. Preset the STAM (STAD) to obtain at least 3 kPa for design flow.
3. Adjust the set point ΔpL of the differential pressure controller STAP to obtain in STAM (STAD)the design flow.

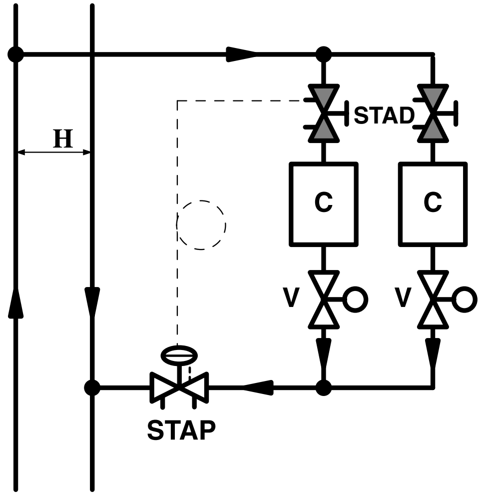


Fig. 4. A differential pressure controller STAP stabilises the differential pressure across a set of terminal units.

When several small terminal units ”C” are close to each other, it can be sufficient to stabilise the differential pressure on the whole set according to figure 4.

The supply pressure is transmitted to the STAP by means of a capillary mounted on the entering of the balancing valve of the first circuit.

When the differential pressure ΔH increases, the valve STAP shuts to compensate. Each control valves ”V” is chosen to create, fully open and at design flow, approximately the same pressure drop as its coil unit.

Balancing procedure fig 4

1. Keep the set point of the STAP as it comes from the factory. The control valves ”V” are fully open
2. Balance the terminals of the branch according to the TA Balance method (Handbook 2) which does not depend on the differential pressure ΔH available.
3. Adjust the set point of the STAP to obtain the design flow through the balancing valve STAD of the first circuit. The flows will be automatically correct in the other circuits.

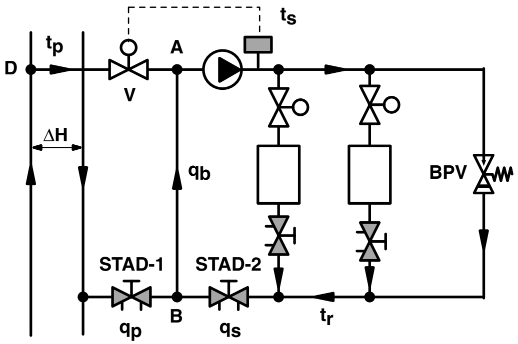


Fig.5. A secondary pump creates a sufficient differential pressure. The secondary water temperature is necessarily different from that of the primary.

If the differential pressure ΔH is too low to give a reasonable authority for the coil control valves, a secondary pump can create a sufficient differential pressure.

The solution in Fig 5 can also be used when the primary differential pressure is too high.

The secondary water temperature ts can be constant or variable, but is necessarily different from the primary temperature tp. In heating ts < tp, while in cooling ts > tp.

At low loads, the differential pressure across the secondary tends to increase. When this pressure exceeds a certain value, the BPV opens to allow a minimum flow to protect the pump. This flow also limits the temperature drop in the pipes so that the necessary water temperature is obtained throughout the secondary network.

Balancing procedure fig 5

The secondary.

1. Open all control valves fully. Close the BPV.
2. Balance the coils in the secondary system with STAD-2 as the Partner valve (see TA manual No 2).
3. Set the BPV on the maximum allowed Δp for the coil control valves.
4. Close the coil control valves.
5. Set the BPV to obtain the minimum pump flow (see Appendix C).

The primary.

1. Open the control valve V.
2. If the primary flow is unknown, calculate it using the formula on page 15.
3. Adjust the primary design flow with STAD-1. Do this as part of the balancing procedure for the entire primary system (see TA manual No 2).

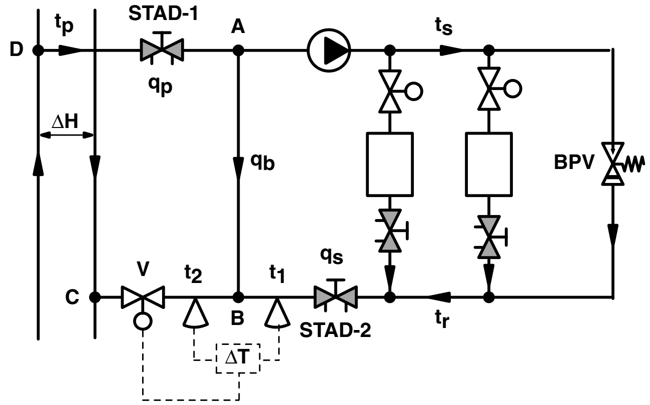


Fig.6. A differential temperature controller maintains a minimum flow qb in the bypass, such that ts = tp.

If the secondary water temperature must be equal to that of the primary, the circuit in Fig 6 (heating only) or the circuit in Fig 7 (both heating and cooling) may be used.

To obtain ts = tp, the flow qb through the bypass must be greater than zero. A ΔT controller acts on the primary control valve V to ensure a minimum flow qb in the right direction. The ΔT controller keeps t2 slightly higher than t1. Normally, the setpoint of the ΔT controller is between 1 and 2 degrees.

Balancing procedure fig 6

The secondary.

1. Open all control valves. Close the BPV.
2. Balance the coils in the secondary system with STAD-2 as the Partner valve (see TA manual No 2).
3. Set the BPV on the maximum allowed Δp for the coil control valves.
4. Close the coil control valves.
5. Set the BPV to obtain the minimum pump flow (see Appendix C).

The primary.

1. Open the control valve V.
2. If the primary flow is unknown, calculate it using the formula below.
3. Adjust to primary design flow with STAD-1. Do this as part of the balancing procedure for the entire primary system (see TA manual No 2).

$$qp = 1.05\ qs$$

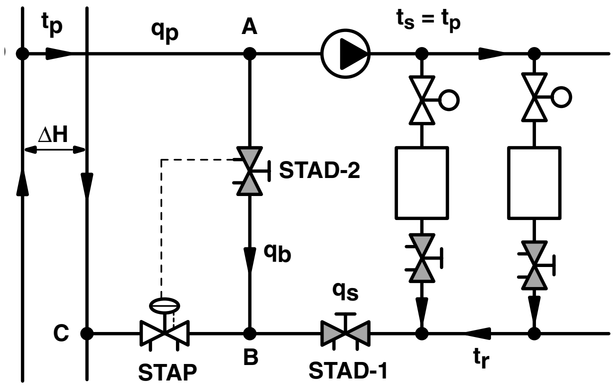


Fig. 7. A differential pressure controller keeps the flow constant in the bypass, ensuring a constant differential pressure across this bypass.

The circuit in Fig 7 may be used in cooling plants where ΔH is too low to give a sufficient authority for the coil control valves, and where ΔH varies greatly.

The control valve STAP maintains a small and constant flow in the bypass, regardless of variations in ΔH. This small flow is measured by means of STAD-2. When ΔH increases, the STAP closes correspondingly, ensuring a constant differential pressure across the balancing valve STAD-2.

Balancing procedure fig 7

1. Open all control valves.
2. Set STAD-2 to create, for 5% of design flow qs, a pressure loss corresponding to the selected setpoint of the Δp controller. Use the CBI, or a TA nomogram, to find the correct setting for STAD-2.
3. Balance the secondary circuit where STAD-1 is the Partner valve (see TA manual No. 2).

3.2 Variable primary flow and constant secondary flow

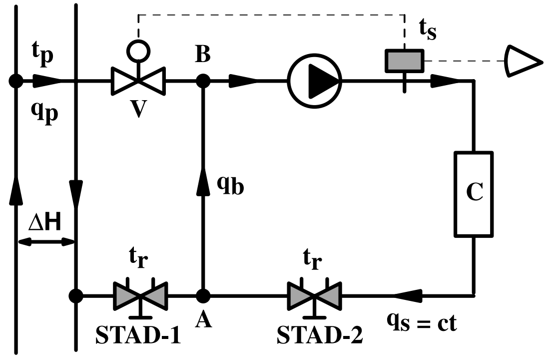


Fig. 8. Control of coil output for a coil supplied at constant flow.

This circuit is frequently used both in heating and in cooling. The coil supply temperature ts is adapted to the power need through control of the primary flow.

If, under design conditions, ts must be equal to tp, the maximum flow qp in the primary must be equal to or greater than the secondary flow qs. Otherwise, the installed power can not be transmitted to the secondary since the design value tsc can not be obtained. Primary and secondary flows must be compatible. These flows are adjusted by the balancing valves STAD-2 and STAD-1.

A floor heating example: Assume that tsc = 50°C, which is well below the tp = 80°C. The control valve must then be selected for a relatively small flow. For a return temperature trc = 45°C, the formula below shows that the primary flow will be only 14% of the secondary flow. If the control valve is selected for this flow, it can operate over its entire range. The limit of 50°C for the circuit supply temperature will not be exceeded at the maximum valve opening. If the secondary pump fails, the primary flow passes through the bypass, preventing overheating in the circuit.

Balancing procedure fig 8

1. Open control valves fully.
2. Adjust to secondary design flow with STAD-2.
3. If the primary flow is unknown, calculate it using the formula below.
4. Adjust the primary flow with STAD-1. Do this as part of the balancing procedure for the entire primary system (see TA manual No 2).

$$q_p = q_s \frac{t_s - t_r}{t_p - t_r} = q_s \frac{50 - 45}{80 - 45} = 0.14\ q_s$$

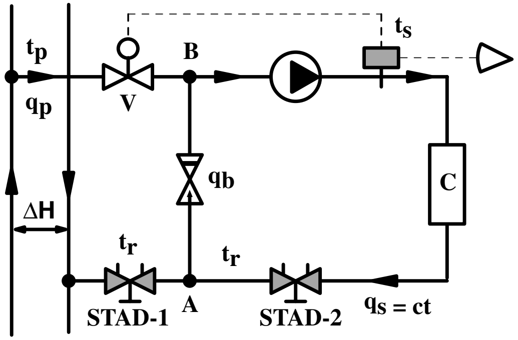


Fig. 9. A check valve in the bypass allows a certain waterflow through the coil C even if the secondary pump fails.

This is essentially the same circuit as in Fig 8. However, a check valve is added to prevent circulation in direction BA in the bypass.

If the circuit is used in district heating and the primary control valve is oversized, the check valve prevents heating of the return water. If the circuit is used for a heating coil in contact with outside air, the check valve eliminates the risk of freezing due to secondary pump failure.

Note that it's impossible to obtain a primary flow greater than the secondary flow.

Balancing procedure fig 9

tsc equal to tp:

1. Close the control valve V.
2. Adjust to secondary design flow qsc with STAD-2.
3. Open the control valve V.
4. Adjust the primary flow to the same flow qsc with STAD-1. Do this as part of the balancing procedure for the entire primary system (see TA manual No 2).

tsc not equal to tp:

1. Close the control valve V.
2. Adjust to secondary design flow with STAD-2.
3. If primary flow is unknown, calculate it using the formula below.
4. Open the control valve.
5. Adjust the primary design flow with STAD-1. Do this as part of the balancing procedure for the entire primary system (see TA manual No 2).

$$q_p = q_s \frac{(t_s - t_r)}{(t_p - t_r)}$$

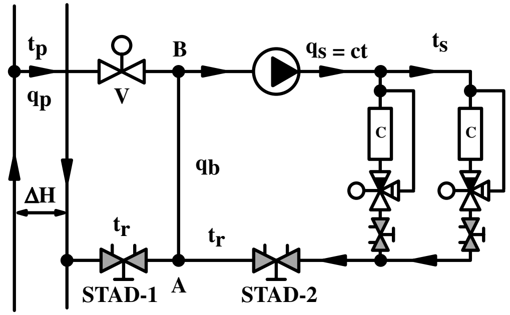


Fig. 10. A primary constant flow distribution converted to primary variable flow.

It's common to convert existing constant water flow distribution systems into variable flow in large plants. There are three reasons: 1) The supply water temperature can then be kept constant without having to keep in service all production units at all loads. 2) A variable distribution flow means reduced pumping costs. 3) The plant can be designed with a diversity factor.

Normally, the secondary side continues to work with constant flow.

After conversion, we cannot work with ts=tp. When the valve V is completely open, we can get ts=tp with flow reversal in the bypass. Since the demand is satisfied in this situation, there is no signal to make the two-way valve close. It remains open and we are back to a constant flow distribution system. To avoid this, ts has to be adjusted so that ts < tp in heating and ts > tp in cooling.

The primary flow will vary as a function of the load:

$$q_p = \frac{P}{1 + \frac{(t_{sc} - t_{rc})}{(t_p - t_{rc})} \left(\frac{P}{100} - 1\right)} \%$$

P is the load in percent of design power.

Now assume that tp=6°C, tsc=8°C and trc=12°C. For P=50%, we get qp=75%. Thus the flow demand is 75% for a power demand of 50%.

Before converting the constant flow system into a variable flow system, the flow demand was 100% for a power demand of 50%.

This conversion does not change really the primary into a true variable distribution as the flow in % remains higher than the power in %.

Balancing procedure fig 10

1. Balance the three-way valve circuits (see TA manual No 2). STAD-2 is the Partner valve.
2. If the primary flow qp is unknown, calculate it using the formula below.
3. Open the control valve V.
4. Adjust the primary flow qp with STAD-1. Do this as part of the balancing procedure for the entire primary system (see TA manual No 2).

$$q_p = q_s \frac{(t_s - t_r)}{(t_p - t_r)}$$

Fig 11a *Fig 11b*

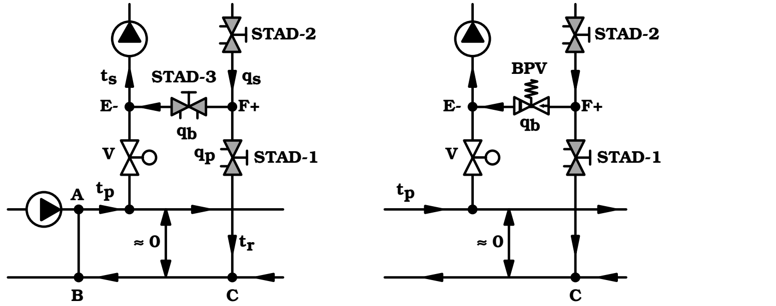


Fig. 11. Secondary pumps induce flow through the distribution network.

If the distribution network is a low pressure loss passive circuit, circulation may be induced by secondary pumps.

The balancing valve STAD-3 creates a certain differential pressure between F and E. This pressure generates the primary flow qp in the control valve V, through FCB and AE. The differential pressure ΔpcEF is obtained for qb= qsc-qpc. This implies that qsc has to be greater than qpc. When the control valve V is closed, the bypass flow qb=qsc and ΔpEF is at its maximum. This is also the differential pressure applied across the closed control valve V. To obtain a good authority for this valve, it's important to avoid big changes in ΔpEF. This means that qpc has to be as small as possible compared to qsc. Consequently, this system can only be considered if there is a large difference between ts and tp, as for example in floor heating.

The flow through the bypass is given by this formula:

$$q_b = q_s \frac{(t_p - t_s)}{(t_p - t_r)}$$

Assuming that the secondary flow qs is more or less constant, the control valve authority ß' = ΔpcV/ΔpEFmax.

Example: Floor heating with tp = 80°C, ts = 50°C, tr = 45°C and qs = 100. At full load, qb = 100 (80-50)/(80-45) = 85.7. At this flow, the balancing valve STAD-3 in the bypass must create a differential pressure that compensates for the pressure loss of the two-way valve (8 kPa for instance) and of the primary circuit (5 kPa), a total of 13 kPa. When the two-way valve is closed, at zero load, the flow qb changes to 100 (assuming that the increase in the pressure loss EF has little effect on the flow qs) and the pressure loss in the STAD-3 becomes ΔpEFmax = 13 x $(100/85.7)^2$ = 18 kPa.

The control valve authority is therefore ß' = 8/18 = 0.44.

The STAD-3 can be replaced by a modulating relief valve BPV (Fig 11 b) which keeps a constant differential pressure EF. In the floor heating example, this improves control valve authority from 0.44 to 0.61.

Balancing procedure fig 11

STAD-3 in the bypass (Fig 11a):

1. Open all control valves fully.
2. Set the STAD-3 to create a pressure loss ΔpEF = ΔpcV+ pressure drop in the primary circuit (8+5=13 kPa in our example) for a flow rate qb = (qsc - qpc) in the bypass. Use the CBI, or the TA nomogram, to find the correct handwheel setting for STAD-3.
3. Set the STAD-1 to create a pressure loss of 3 kPa for primary design flow. Use the CBI, or a TA nomogram, to find the correct handwheel setting for STAD-1
4. Close the control valve V. Adjust to design flow with STAD-2.
5. If the primary flow qpc is unknown, calculate it using the formula below.
6. Open the control valve V. Readjust STAD-3 to obtain qp= qpc measured in STAD-1.

$$q_p = q_s \frac{(t_{sc} - t_{rc})}{(t_p - t_{rc})}$$

BPV in the bypass (Fig 11b):

1. Open all control valves fully.
2. Set the STAD-1 to create a pressure loss of 3 kPa for qp=qpc. Use the CBI, or a TA nomogram, to find the correct handwheel setting for STAD-1.
3. Open STAD-2. Adjust the BPV to obtain design flow in STAD-1.
4. Adjust STAD-2 to obtain design flow in the secondary.

3.3 Constant primary flow and variable secondary flow

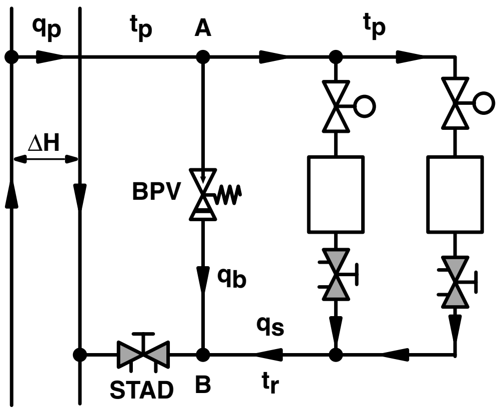


Fig. 12. A modulating relief valve BPV stabilizes the differential pressure applied to small units.

When the available differential pressure on the primary is too high for the secondary, the circuit in Fig 12 may be used.

The setpoint of the BPV can be selected within a range from 8 to 60 kPa. This makes it possible to ensure good working conditions for the coil control valves (good authority) regardless of variations in the differential pressure ΔH. The BPV ensures a constant differential pressure between A and B. STAD creates a pressure loss of (ΔH - ΔpBPV).

Balancing procedure fig 12

1. Open all control valves. Close all BPVs.
2. Balance the coils against each other, the branch against other branches and the riser against other risers (see TA manual No 2). Do this before you proceed to step 3.
3. Close the control valves of this branch.
4. Reduce the BPV setpoint slowly until you get back to 2/3 of the design flow in STAD.
(See also handbook 4 - appendix 5.5 for complementary explanations).

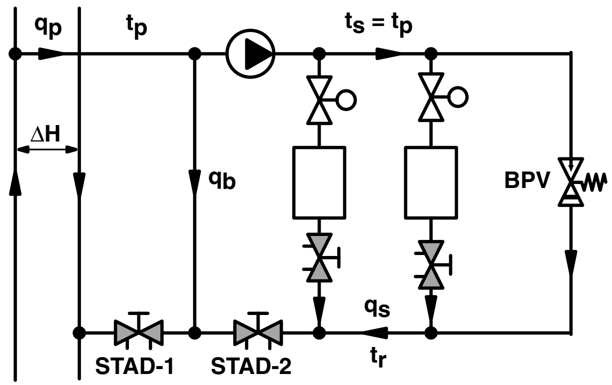


Fig. 13. Reducing or increasing the differential pressure applied across coils by means of a secondary pump.

When the primary differential pressure is too high or too small for the secondary, the circuit in Fig 13 presents a possible solution. In this circuit, a relief valve is used to obtain a minimum flow to protect the pump. STAD-1 is essential to avoid short-circuiting the primary system.

Balancing procedure fig 13

1. Open all control valves. Close all BPVs.
2. Balance the coils against each other with STAD-2 as the Partner valve (see TA manual No 2).
3. Set the BPV on the maximum permitted differential pressure for the coil control valves.
4. Close the coil control valves of this branch.
5. If necessary, reduce the BPV setpoint until you obtain the minimum pump flow (see Appendix C).
6. Adjust to primary design flow with STAD-1. Do this as part of the balancing procedure for the entire primary system (see TA manual No. 2).

3.4 Constant primary and secondary flow

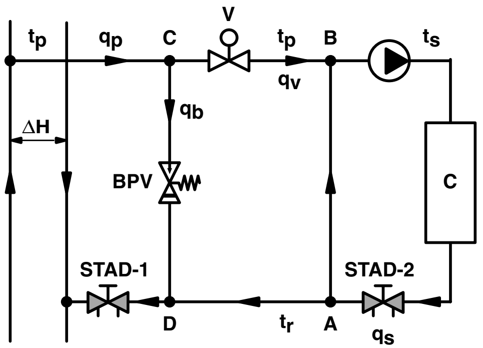


Fig. 14. Constant primary and secondary flows.

A coil is supplied at constant flow. The supply water temperature is modified by the two-way control valve V. This temperature has to be adjusted so that ts < tp in heating and ts > tp in cooling. The BPV keeps the differential pressure CD constant. This is the design pressure loss for the control valve V, which has an authority close to 1 after balancing.

Balancing procedure fig 14

1. Open all control valves. Close all BPVs.
2. If the primary flow is unknown, calculate it using the formula below.
3. Adjust the primary flow with STAD-1. Do this as part of the balancing procedure for the entire primary system (see TA manual No 2) and before you proceed to step 4.
4. Close the control valve V.
5. Measure the flow in STAD-1. Reduce the BPV set point slowly until you get back to 2/3 of the design flow in STAD-1.
6. Adjust the secondary design flow with STAD-2.

$$q_p = q_s \frac{(t_{sc} - t_{rc})}{(t_p - t_{rc})}$$

(See also handbook 4 - appendix 5.5 for complementary explanations).

4.1 Variable primary flow and constant secondary flow

Passive primary network

A passive primary network is a distribution network without a pump. The secondary pump pressurizes both the primary and the secondary.

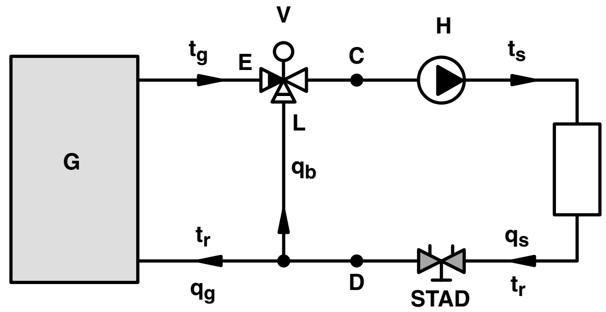


Fig. 15. Mixing circuit associated with a production unit.

Fig 15 shows a circuit controlled by a three-way mixing valve. The primary circuit consists of an exchanger, a bypass line or a boiler that can either accept zero flow or be equipped with a bypass pump that generates a minimum flow. The three-way valve should be selected for a pressure loss at least equal to that in G, and at least 3 kPa.

Balancing procedure fig 15

1. Open the three-way valve completely.
2. Adjust to design flow with STAD.

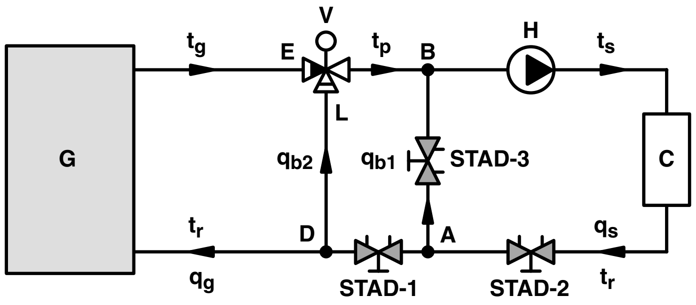


Fig. 16. Mixing circuit with intermediate bypass.

When the flow q_s in the circuit is greater than the design flow through the production unit, a bypass AB insures compatibility between the flows.

The pressure drop created by the STAD-3 , for a water flow $q_{b1} = q_{sc} - q_{gc}$, is the necessary differential pressure to compensate the pressure drops in the STAD-1 + G + the 3-way valve.

The pressure drop created by the three-way control valve for the design flow q_{gc} must be equal or higher than the design pressure drop in G and accessories with a minimum of 3 kPa.

Balancing procedure fig 16

1. Open the three-way control valve ”V”.
2. Calculate the design flow q_{b1} required in the STAD-3 and the flow q_{gc} in STAD-1 with formula below.
3. STAD-3 and STAD-1 are balanced according to the TA Balance method (See Handbook 2 - version 2).
4. Adjust the flow q_s with the STAD-2.

$$q_{gc} = q_{sc} \frac{(tsc- trc)}{(tg- trc)} \qquad q_{b1} = q_{sc} - q_{gc}$$

Active primary network

An active primary network is a distribution system with its own pump.

The primary pump creates a differential pressure which forces the water flow through the secondary circuits.

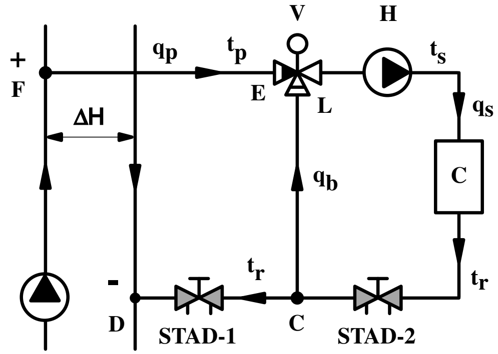


Fig. 17. Mixing valve with differential primary pressure and compensation balancing valve.

The three-way valve in Fig 17 is supplied by a primary differential pressure ΔH. This pressure may disturb the function of the three-way valve. The water flow qb in the bypass may reverse and cancel the mixing function of the control valve.

To prevent this, the balancing valve STAD-1 has been installed. The pressure loss in STAD-1 should be ΔH for design flow qpc.

The design pressure loss across the three-way valve must be at least equal to ΔH to give an authority of 0.5. This pressure loss has to be covered by the secondary pump.

Balancing procedure fig 17

1. Close the three-way valve.
2. Adjust to secondary design flow with STAD-2
3. Open the three-way valve.
4. Continue to measure the flow with STAD-2. Adjust STAD-1 to obtain the same flow as in step 2. Do this as part of the balancing procedure for the entire primary system (see TA manual No 2).

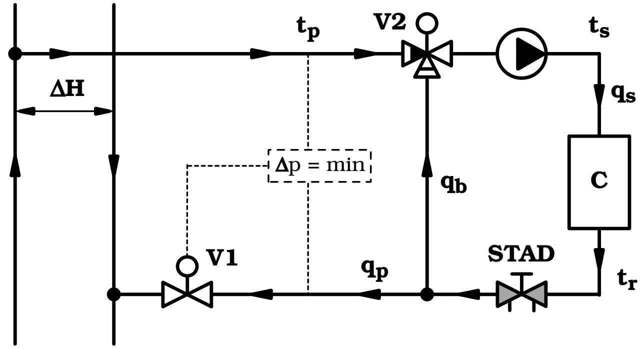


Fig. 18. Elimination of the primary differential pressure by means of a pressure controller.

In some plants the three-way valves do not work satisfactorily because of a too high primary differential pressure. Sometimes a differential pressure controller is installed to eliminate or reduce this pressure to a reasonable value, as shown in Fig 18.

This is an expensive solution. However, it may be considered if the differential pressure controller is used to supply several 3-way valves and when a variable flow system is required in the distribution. If a constant primary flow is accepted, the design of figure 20 is better.

Balancing procedure fig 18

1. Close the three-way valve.
2. Adjust to secondary design flow with STAD.
3. Adjust the setpoint of the differential pressure controller to a value as low as possible.

4.2 Variable primary and secondary flows

Passive primary network

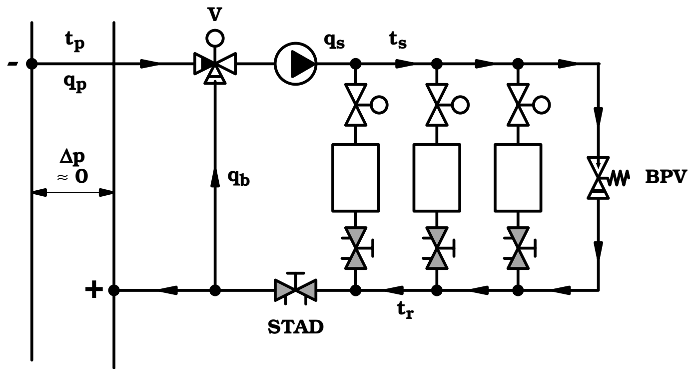


Fig. 19. The three-way valve prepares the water temperature in the distribution system.

The three-way valve controls the secondary water temperature. The two-way control valves make the fine tuning of the energy supply by adapting the flow to the demands.

The three-way valve has an authority close to 1. At low loads, the modulating relief valve BPV ensures a minimum pump flow, and also reduces the temperature drop in the pipe line.

Note: Below a certain flow, a three-way valve will work with laminar rather than turbulent flow. Then the three-way valve temporarily loses its basic characteristics and the control loop becomes difficult to stabilize. Thus, the minimum flow controlled by the BPV must be high enough to create a pressure loss of at least 1 kPa in the three way valve.

Balancing procedure fig 19

1. Open all control valves. Close the BPV.
2. Balance the secondary system (see TA manual No 2) with STAD as the Partner valve.
3. Close all two-way control valves.
4. Set the BPV to obtain the minimum pump flow (see Appendix C).

4.3 Constant primary and secondary flows

Active primary network

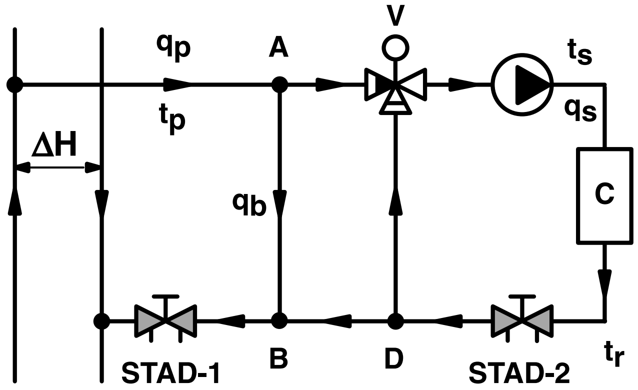


Fig. 20. The balancing valve STAD-1 and the bypass AB, eliminate the primary differential pressure across the three-way valve.

If the primary flow may be constant, it's simple to avoid a too high differential pressure on the primary of a mixing three-way valve. It's just to install a bypass AB and to compensate the primary differential pressure with the balancing valve STAD-1. The authority of the three-way valve will then be close to 1.

Balancing procedure fig 20

1. Open the three-way valve.
2. Adjust to secondary design flow with STAD-2.
3. If the primary flow qp is unknown, calculate it using the formula below.
4. Adjust the primary flow with STAD-1. Do this as part of the balancing procedure for the entire primary system (see TA manual No. 2).

$$q_p = q_s \frac{(t_{sc} - t_{rc})}{(t_p - t_{rc})}$$

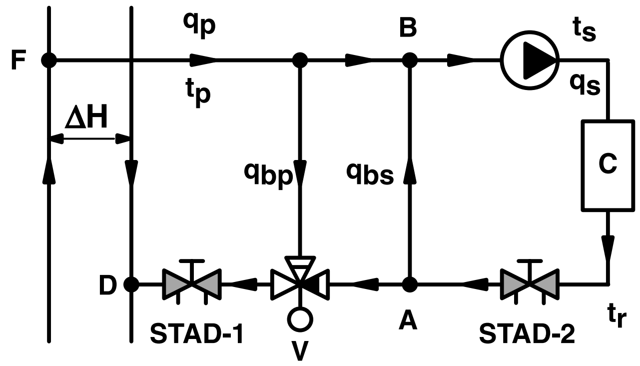


Fig. 21. When tsc is not equal to tp, it is better to place the bypass on the secondary side.

When the design temperature tsc is not equal to tp, the circuit in Fig 21 is often preferable to that in Fig 20.

The flow in the control valve is lower in Fig 21 than in Fig 20 (qp instead qs), thus allowing the use of a smaller three-way valve.

The authority of the three-way valve is close to 1.

Balancing procedure fig 21

1. Open the three-way valve.
2. Adjust to secondary design flow with STAD-2.
3. If the primary flow qp is unknown, calculate it using the formula below.
4. Adjust the primary flow with STAD-1. Do this as part of the balancing procedure for the entire primary system (see TA manual No. 2).

$$q_p = q_s \frac{(t_{sc} - t_{rc})}{(t_p - t_{rc})}$$

4.4 Constant primary flow and variable secondary flow

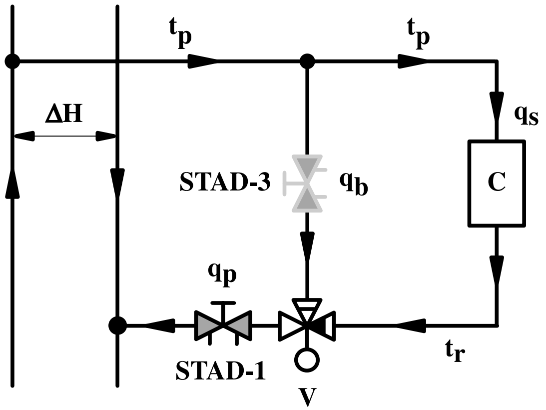


Fig. 22. A three-way mixing valve in a diverting circuit.

The three-way valve used as a mixing valve in a diverting circuit can supply the coil at variable flow and constant water supply temperature, while keeping primary flow constant. This way, the three-way valve eliminates interactivity between circuits on the primary side.

The three-way valve should create a design pressure loss equal to or greater than the pressure loss in circuit C to ensure an authority of at least 0,5.

Note: The most important balancing valve is the STAD-1. STAD-3 can be omitted if $\Delta pC < 0.25\ \Delta H$.

Balancing procedure fig 22

1. Open all three-way valves.
2. Adjust to design flow with STAD-1. Do this as part of the balancing procedure for the entire primary system (see TA manual No 2) and before you proceed to step 3.
3. Close the three-way valve.
4. Measure the flow in STAD-1. Adjust to design flow with STAD-3.

4. Control loops with three-way control valves

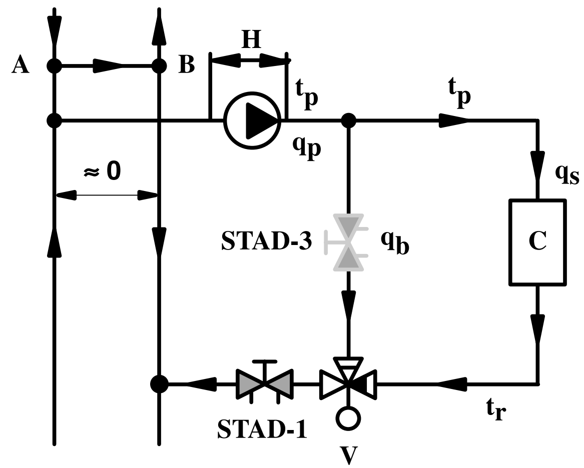


Fig. 23. Circuit in diversion on a passive distribution.

If the distribution system is passive (no active differential pressure), there is a need for a separate pump. This pump can be common to several circuits.

Note: The most important balancing valve is STAD-1. STAD-3 can be omitted if $\Delta pC < 0.25$ H.

Balancing procedure fig 23

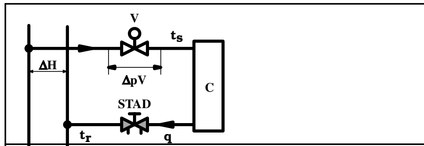
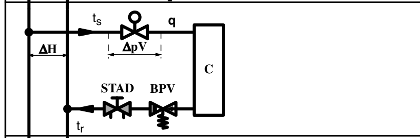
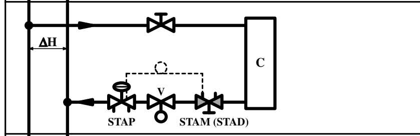
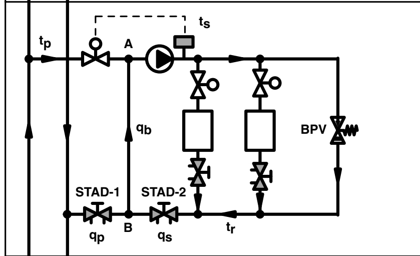
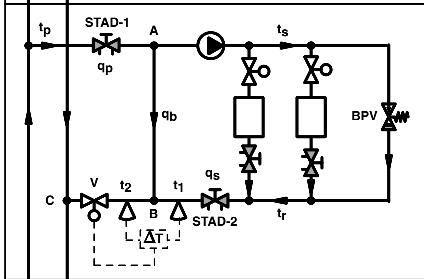
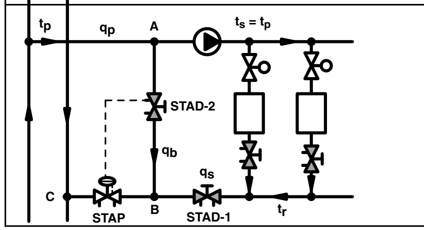
1. Open all three-way valves.
2. Adjust to design flow with STAD-1. Do this as part of the balancing procedure for the entire primary system (see TA manual No 2) and before you proceed to step 3.
3. Close all three-way valves.
4. Measure the flow in STAD-1. Adjust to design flow with STAD-3.

5. Control loops compared

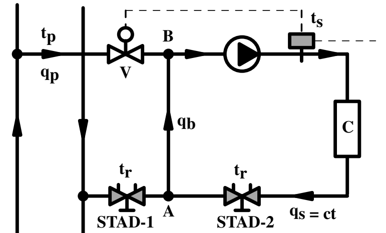
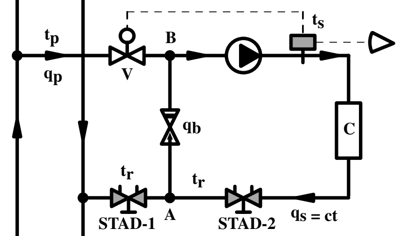
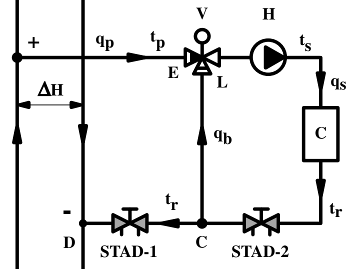
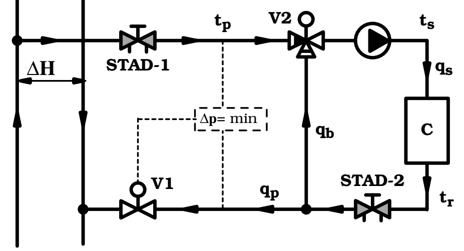
Variable primary water flow			
Variable secondary water flow		Constant secondary water flow	
2 way 3 way	5 19	2 way 3 way	8 - 9 - 10 17 - 18
Constant primary water flow			
Variable secondary water flow		Constant secondary water flow	
2 way 3 way	12 - 13 22	2 way 3 way	14 20 - 21

Same functions obtained with two way or three way control valves.

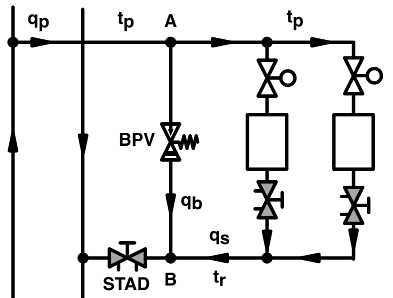
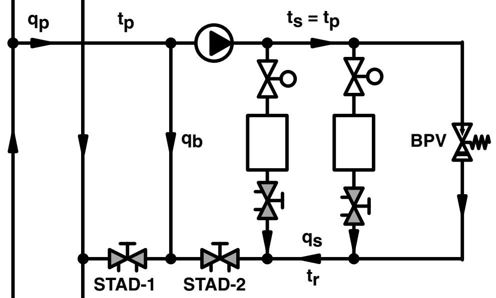
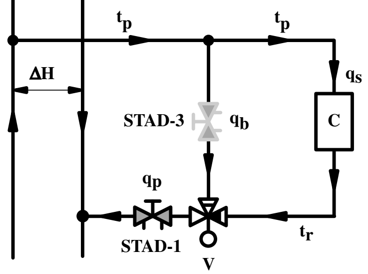
5.1 Active primary network

	1	$\Delta pV > \Delta H/2$ * $\Delta p_{STAD} = \Delta H - \Delta pV - \Delta pC$ $\beta' = \Delta pV / \Delta H$
	2	$\Delta pV > (\Delta H - \Delta p_{BPV})/2$ * $\Delta p_{STAD} > 3$ kPa $\Delta p_{BPV} = \Delta H - \Delta pV - \Delta pC - \Delta p_{STAD}$ $\beta' = \Delta pV / (\Delta H - \Delta p_{BPV})$
	3	$\Delta pV >$ Min STAP set point ≥ 10 kPa $\Delta p_{STAM\ (STAD)} \geq 3$ kPa β' close to one
	5	$q_s < q_p$ $\Delta pV > \Delta H/2$ * $\Delta p_{STAD-1} = \Delta H - \Delta pV$ $\beta' = \Delta pV / \Delta H$
	6	$t_s = t_p$ $q_s < q_p$ $\Delta pV > \Delta H/2$ * $\Delta p_{STAD-1} = \Delta H - \Delta pV$ $\beta' = \Delta pV / \Delta H$
	7	$t_s = t_p$ $\Delta pV > \Delta H/2$ * $\Delta p_{STAD-1} = \Delta H - \Delta pV - \Delta p_{STAD-2}$ $\beta' = \Delta pV / \Delta H$

Variable primary and secondary water flows.
Variables are represented by their design values - Values recommended (*).

	**8**	$q_s < q_p$ $\Delta pV > \Delta H/2$ * $\Delta p_{STAD-1} = \Delta H - \Delta pV$ $\beta' = \Delta pV / \Delta H$
	**9**	$q_s < q_p$ $\Delta pV > \Delta H/2$ * $\Delta p_{STAD-1} = \Delta H - \Delta pV$ $\beta' = \Delta pV / \Delta H$
	**17**	$\Delta pV > \Delta H$ * $\Delta p_{STAD-1} = \Delta H$ $\beta' = \Delta pV / (\Delta pV + \Delta pH)$
	**18**	$\Delta pV1 > \Delta H/2$ * $\Delta pV2 > 3$ kPa * $\Delta p_{STAD-1} = \Delta H - \Delta pV1$ $\beta'_{V1} = \Delta pV1 / (\Delta H - \Delta p)$

Variable primary water flow and constant secondary water flow. Variables are represented by their design values - Values recommended (*).

	**12**	$t_s = t_p$ $\Delta p_{STAD-1} = \Delta H - \Delta p_{BPV}$
	**13**	$t_s = t_p$ $\Delta p_{STAD-1} = \Delta H$
	**22**	$t_s = t_p$ $\Delta pV > \Delta pC$ * $\Delta p_{STAD-3} = \Delta pC$ $\Delta p_{STAD-1} = \Delta H - \Delta pV - \Delta pC$ $\beta' = \Delta pV / (\Delta pV + \Delta pC)$

Constant primary water flow and variable secondary water flow. Variables are represented by their design values - Values recommended (*).

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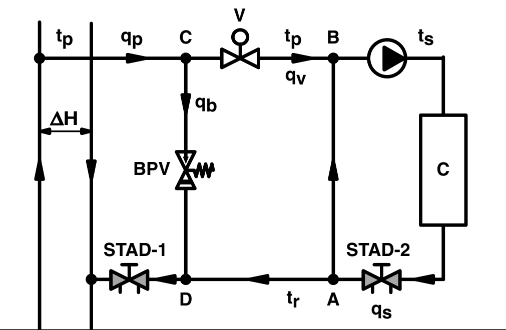
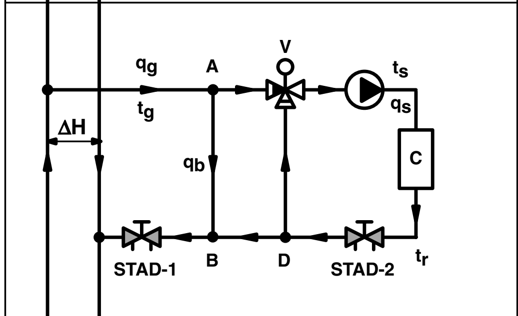
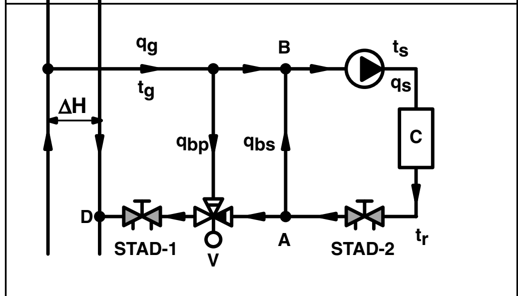
<tr><td></td><td>14</td><td>$q_s > q_p$
$\Delta pV > 8$ kPa
$\Delta p_{STAD-1} = \Delta H - \Delta p_{BPV}$
$\beta' = \Delta pV / \Delta p_{BPV}$</td></tr>
<tr><td></td><td>20</td><td>$\Delta pV > 3$ kPa *
$\Delta p_{STAD-1} = \Delta H$
$\beta' = 1$</td></tr>
<tr><td></td><td>21</td><td>$\Delta pV > 3$ kPa *
$\Delta p_{STAD-1} = \Delta H - \Delta pV$
$\beta' = 1$</td></tr>
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Constant primary and secondary water flows.
Variables are represented by their design values - Values recommended (*).

5.2 Passive primary network

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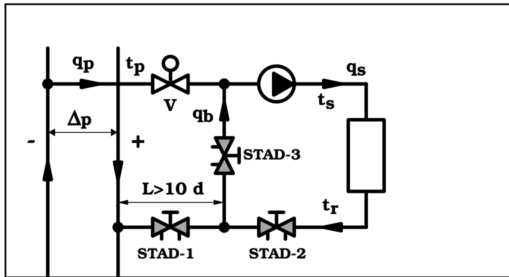
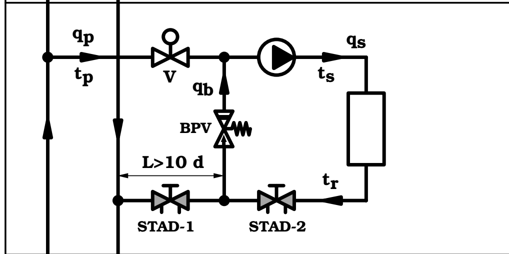
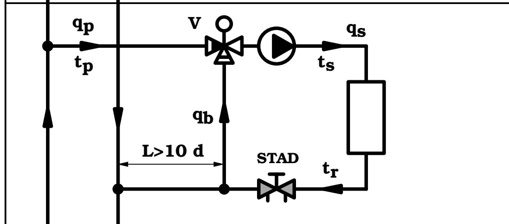
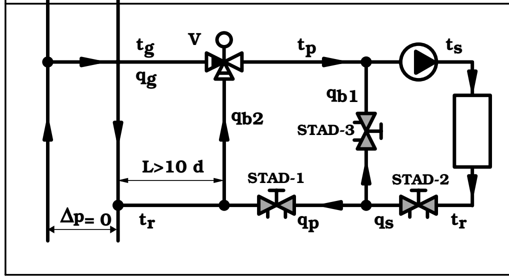
<tr><td></td><td>(11a)</td><td>$q_p < q_s$
$\Delta p_{STAD-3} =$
$\Delta p1 + \Delta pV + \Delta p_{STAD-1}$
$\Delta p_{STAD-1} \geq 3$ kPa *
$\Delta pV \geq \Delta p_{STAD-3} / 2$ *
$\beta' = \Delta pV / \Delta p_{STAD-3}max$</td></tr>
<tr><td></td><td>(11b)</td><td>$q_p < q_s$
$\Delta p_{BPV} =$
$\Delta p1 + \Delta pV + \Delta p_{STAD-1}$
$\Delta p_{STAD-1} \geq 3$ kPa *
$\Delta pV \geq \Delta p_{STAD-3} / 2$ *
$\beta' = \Delta pV / \Delta p_{BPV}$</td></tr>
<tr><td></td><td>(15)</td><td>$\Delta pV > \Delta p1$ *
$\beta' = \Delta pV / (\Delta pV + \Delta p1)$</td></tr>
<tr><td></td><td>(16)</td><td>$q_p < q_s$
$\Delta pV > \Delta p1$ *
$\beta' = \Delta pV / (\Delta pV + \Delta p1)$</td></tr>
</table>

Variable primary water flow and constant secondary water flow.
Variables are represented by their design values - Values recommended (*).

Appendix A
The authority of two-way control valves

A.1 The incomplete definition of valve authority

The static characteristic of a control valve is defined for a constant differential pressure across the valve. But this pressure is rarely constant in a plant. Therefore, the real characteristic of a control valve is not the same as the theoretical one.

When the control valve is fully open, the differential pressure Δpmin is equal to the available differential pressure minus pressure losses in terminal unit, pipes and accessories.

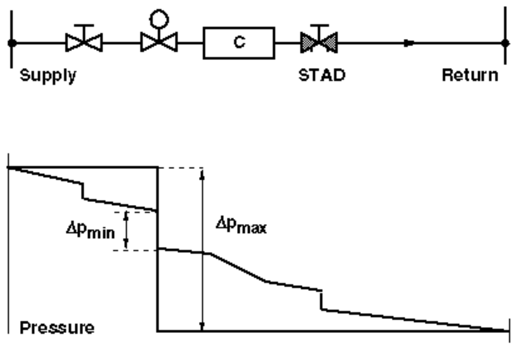
When the control valve is closed, pressure losses in the other elements disappear since the flow is zero. The entire available differential pressure ΔHmax=Δpmax is then applied across the control valve.

But the control valve is sized based on Δpmin since it is at this pressure loss the design flow is to be obtained (fully open valve).

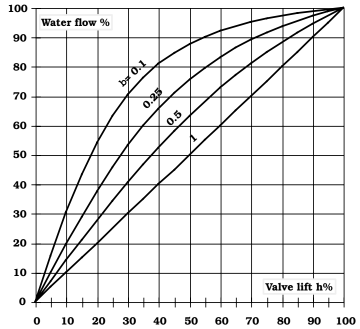
When the valve is near its closed position, the real flow is higher than the theoretical since the differential pressure is greater than Δpmin. The theoretical characteristic is distorted. The degree of this distortion depends on the ratio Δpmin/Δpmax.

This ratio is the control valve authority.

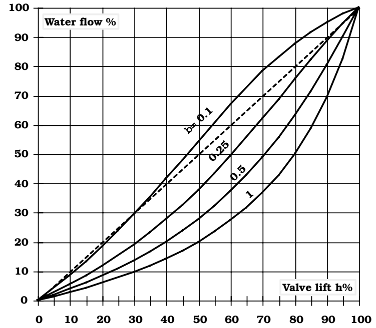
$$\beta = \frac{\Delta p_{min}}{\Delta p_{max}}$$



The differential pressure applied to the control valve depends on its degree of opening.



Distortion of a linear valve characteristic as a function of its authority.



Distortion of the "EQM" characteristic of a valve as a function of its authority.

The lower the authority, the bigger the distortion of the theoretical valve characteristic.

Consider a valve with a linear characteristic, designed to obtain the design flow exactly at full opening, but with a fairly low authority of 0.1. At a 10% valve lift, the flow in the circuit is about 30%.

Suppose that the terminal unit is a heating coil with a design temperature drop of 10K. Then 30% of the water flow produces 80% of the design power.

The final result is that the coil output is 80% of the design power at a control valve lift of only 10%. Under these conditions there is little hope to obtain stable control. The situation would be even worse if, for the same authority, the control valve was oversized!

An authority of 0.5 is acceptable since it does not greatly deform the valve characteristic. In other words, the pressure loss at design flow in a fully open control valve must be equivalent to at least half the available differential pressure.

Note that the design flow does not appear in the definition of valve authority.

The curves in the figures above are plotted assuming design flow when the control valve is fully open. But that is rarely the case in practice, since it is difficult to avoid a certain degree of oversizing.

When a control valve is oversized, Δpmin is reduced, assuming constant Δpmax. Thus, the control valve authority is also reduced. The theoretical valve characteristic will be heavily distorted and control becomes difficult at small loads.

However, an oversized control valve can have a good authority. If the differential pressure applied to a circuit is doubled, Δpmin and Δpmax increase in the same proportion and the authority remains unchanged, although there's now an overflow in the circuit.

What, then, will happen to the valve authority in a circuit exposed to a variable differential pressure?

Then Δpmax and Δpmin will vary simultaneously in the same proportions. The valve authority ß thus remains constant.

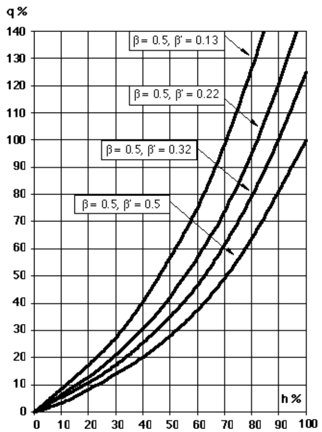
However, the valve characteristic is deformed, despite the fact that the authority ß is the same.

Therefore, the authority as defined above, does not give enough information about the real distortion of the valve characteristic.

A.2 The correct definition of valve authority ß'

We get a more coherent definition of the authority if we relate the pressure loss in the control valve for design flow to the maximum pressure loss in the valve:

$$\beta' = \frac{\Delta p \text{ across the fully open control valve and design flow}}{\Delta p \text{ valve shut}}$$



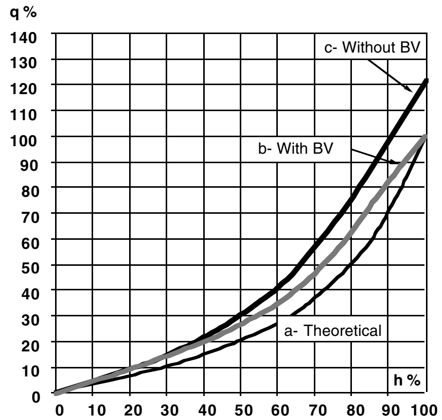
Flow as a function of valve lift when the circuit supply pressure varies with constant authority ß.

The figure shows that the authority ß' takes into account the distortion of the valve characteristic. This is not true for the authority ß according to the conventional definition.

The two authority factors relate to each other according to the formula below (Sq is the overflow factor):

$$\beta = (S_q)^2 . \beta'$$

Sq ≥ 1 with the valve open. When the maximum flow is equal to design flow, ß= ß'.



Influence on the control valve characteristic through limiting the maximum flow by a balancing valve.

Can a balancing valve be put in series with a control valve?

A control valve with exactly the calculated Kv-value is usually not available on the market. Consequently, the installed valve is more or less oversized. During start up after night setback, when most control valves are open, the overflow in favoured units creates underflows in others. It's therefore essential that the flow through the control valve is limited by a balancing valve.

The figure above shows how this type of limitation influences the control valve characteristic. Without a balancing valve, the overflow in the fully open control valve will be 22% and its authority ß = 0.5 according to the conventional definition of valve authority. But this is a rather misleading information about the authority, since the flow is wrong.

The authority ß' = 0.34 indicates the real distortion of the valve characteristic.

The authority ß' is the same with or without the balancing valve, and depends mainly on the initial choice of control valve.

By installing a balancing valve, we can obtain the correct water flow under design conditions and **improve** the control valve characteristic.

A.3 Sizing of control valves

The Kv factor.

A control valve creates a complementary pressure loss in the circuit to limit the water flow to the required value. The water flow depends on the differential pressure applied to the valve:

$$q = Kv \sqrt{\frac{\Delta p \times 1000}{\rho}}$$

Kv is the valve flow factor.

ρ is the density. For water, ρ =1000 kg/m3 at 4°C and ρ = 970 at 80°C.
q is the liquid flow in m3/h.

Δp is the differential pressure expressed in bars.

The maximum Kv value (Kvs) is obtained when the valve is fully open. This value corresponds to the water flow expressed in m3/h, for a differential pressure of 1 bar.

The control valve is selected so that its Kvs value will give design flow for the differential pressure available when the valve is working under design conditions.

It is not easy to determine the Kvs needed for a control valve since the available differential pressure for the valve depends on many factors:

- The actual pump head.
- Pressure losses in pipes and accessories.
- Pressure losses in terminal units.

These pressure losses also depend on the precision with which balancing is done.

During the design of the plant, the theoretically correct values for pressure losses and flows for various components are calculated. But components with exactly the specified properties are rarely available. The installer must normally select standard values for pumps, control valves and terminal units.

Control valves, for instance, are available with Kvs values which increase in a geometric progression, called a Reynard series:

Kvs: 1.0 1.6 2.5 4.0 6.3 10 16 .....

Each value is about 60% greater than the previous value.

It is unusual to find a control valve that creates exactly the desired pressure loss for design flow. If, for instance, a control valve that creates a pressure loss of 10 kPa for the design flow is needed, it may occur that the valve with the nearest higher Kvs value creates a pressure loss of only 4 kPa, while the valve with the nearest lower Kvs value creates a pressure loss of 26 kPa for design flow.

Δp (bar), q (m3/h)	Δp (kPa), q (l/s)	Δp (mm WG), q (l/h)	Δp (kPa), q (l/h)
$q = Kv\sqrt{\Delta p}$	$q = Kv\sqrt{\Delta p}$	$q = 10\ Kv\sqrt{\Delta p}$	$q = 100\ Kv\sqrt{\Delta p}$
$\Delta p = \left(\frac{q}{Kv}\right)^2$	$\Delta p = \left(36\frac{q}{Kv}\right)^2$	$\Delta p = \left(0.1\frac{q}{Kv}\right)^2$	$\Delta p \approx \left(0.01\frac{q}{Kv}\right)^2$
$Kv = \frac{q}{\sqrt{\Delta p}}$	$Kv = 36\frac{q}{\sqrt{\Delta p}}$	$Kv = 0.1\frac{q}{\sqrt{\Delta p}}$	$Kv = 0.01\frac{q}{\sqrt{\Delta p}}$

Some formulas involving the flow, Kv and Δp (ρ = 1000 kg/m³).

In addition, pumps and terminal units are often oversized for the same reason. This means that control valves frequently have to work near their closed position, resulting in unstable control. It is also possible that these valves periodically open to a maximum, definitely during start up, creating an overflow in their unit and underflows in other units. We should therefore ask the question:

What to do if the control valve is oversized?

We have already seen that we usually can't find exactly the control valve that we want.

Take the case of a 2000 watt coil, designed for a temperature drop of 20 K. Its pressure loss is 6 kPa for the design flow of 2000 x 0.86/20 = 86 l/h. If the available differential pressure is 32 kPa and pressure losses in pipes and accessories are 4 kPa, the difference is 32 - 6 - 4 = 22 kPa which must be applied across the control valve.

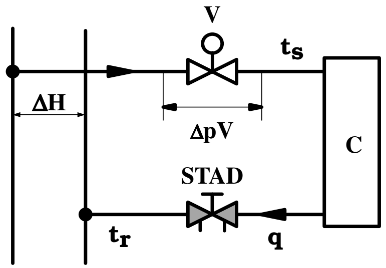
The required Kvs value is 0.183.

If the lowest available Kvs value is 0.25, for example, the flow will be 104 l/h instead of the desired 86 l/h, an increase by 21%.

In variable-flow systems, differential pressures applied to terminal units are variable since pressure losses in pipes depend on the flow. Control valves are selected for design conditions. At low loads, the maximum potential flow in all units is increased and there is no risk of creating underflows in some units. Under design conditions, and when maximum load is required, it's essential to avoid overflows.

a- Flow limitation by means of a balancing valve in series

If the flow in the open control valve under design conditions is greater than the required value, a balancing valve in series can be used to limit this flow. This does not change the real authority of the control valve, and we even improve its characteristic (see figure page 41). The balancing valve is also a diagnostic tool and a shut-off valve.



A balancing valve limits the flow in the control valve without changing its authority ß'

b - Reduction of the maximum valve lift

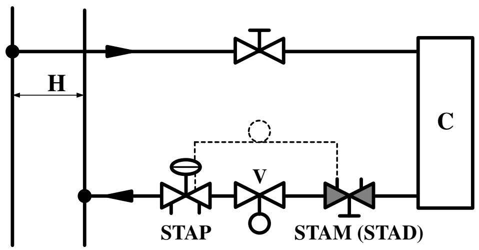
To compensate for oversizing of a control valve, the valve opening may be limited. This solution can be considered for Equal percentage characteristic valves, since the maximum Kv value can be significantly reduced with a reasonable reduction in the maximum opening. If the degree of opening is reduced by 20%, the maximum Kv value is reduced by 50%.

In practice, balancing is carried out by means of balancing valves in series with fully open control valves. The balancing valves are then adjusted in each circuit successively in order to give a pressure loss of 3 kPa at the design flow.

The control valve lift is then limited to create 3 kPa in the balancing valve. Since the plant is and remains balanced, the flow is therefore actually obtained under design conditions.

c- Flow reduction using a Δp control valve in series.

The differential pressure across the control valve can be stabilized according to figure below.



A Δp controller keeps constant the differential pressure across the control valve

The set point of the differential pressure control valve STAP is chosen to obtain the design flow for the control valve fully open. In this case, the control valve is never oversized and its authority is kept close to one. Balancing procedure is described on page 10.

Appendix A
The authority of two-way control valves

Some rules of thumb.

When two-way control valves are used on terminal units, most control valves will be closed or almost closed at low loads. Since water flows are small, pressure losses in pipes and accessories are negligible. The entire pump head is applied across the control valves, which must then be able to resist this pressure. This increase in the differential pressure makes control difficult at small flows, since the real valve authority ß' is reduced greatly.

Assume that a control valve is designed for a pressure loss of 4% of the pump head. If the plant works at small flow, the differential pressure across this control valve increases from 4 to almost 100%. The differential pressure is thus multiplied by 25. For the same valve opening, all flows are then multiplied by 5 ($\sqrt{25} = 5$).

The valve is forced to work near its closed position. This may result in noise and hunting (under these new working conditions, the valve is oversized five times).

This is why some authors recommend that the plant is designed so that the design pressure loss in the control valves is at least 25% of the pump head. Then, at low loads, flow oversizing of control valves does not exceed a factor 2.

It's not always possible to find control valves capable of resisting such large differential pressure without generating noise. It is also difficult to find valves small enough to satisfy the above criterion when low power terminal units are used. Then, differential pressure variations in the plant should be limited, for example by the use of secondary pumps.

Taking this additional concept into consideration, the sizing of a two-way control valve must satisfy the following conditions:

1. When the plant operates under normal conditions, the flow in the fully open control valve must be the calculated flow. If the flow is greater than this, a balancing valve in series will limit the flow. An authority of 0.30 is then acceptable for a PI type controller. If the authority is lower, the control valve should be replaced for a smaller one.

2. The pump head should be such that the pressure loss in the two-way control valves can be selected to be at least 25% of this pump head.

For On-Off controllers, the authority concept is meaningless since the control valve is either open or closed. Its characteristic is therefore not very important. In this case the flow is limited, with no fundamental restriction, by a balancing valve in series.

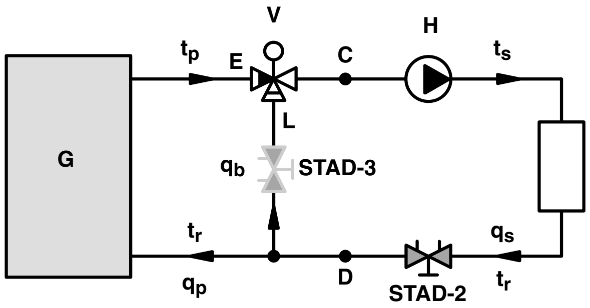
Appendix B

The authority of three-way control valves

B.1 In mixing function

A three-way valve used in mixing can supply a circuit at constant flow and variable inlet water temperature.

The primary water at temperature tp is mixed with the return water at temperature tr in the necessary proportion to obtain the required mix temperature ts.



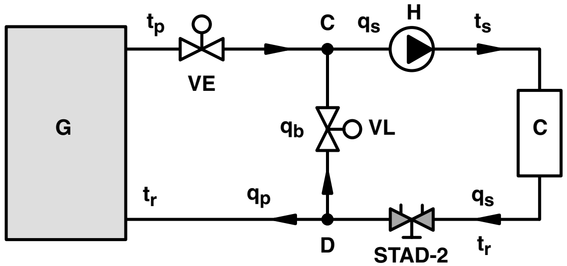
Three way valve in mixing function.

When port E opens, port L closes in the same proportion. The third common port remains open. When port E is closed, the three-way valve is closed and no energy can be extracted from the primary. The temperature ts is then equal to tr which gradually reaches the mean temperature of the room.

The balancing valve STAD-2 can adjust the flow to the required value. In principle, a hydraulic resistance equal to that of G must be created in the bypass by means of STAD-3 in order to give the same water flow qs regardless of whether the three-way valve is open or closed. In this case, the three-way valve is balanced.

The authority of the three-way valve.

We will replace the three-way valve by two two-way valves working in opposition. We will then obtain the same mixing function.



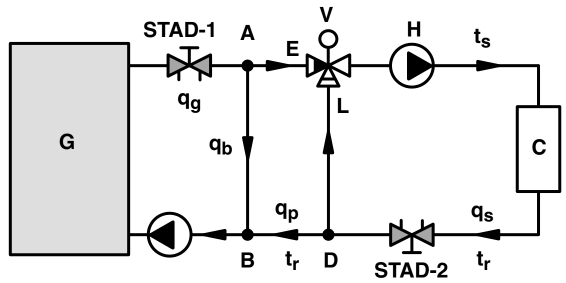
A three-way valve can be represented by two two-way valves working in opposition.

The valve VE represents the control port. Its pressure drop for the design flow = ΔpV. If the circuit flow qs is constant, the pump pressure head H is constant, as are pressure losses in the circuit. The result is that the pressure difference ΔpDC is constant. This pressure difference is applied to valve VE when it is closed. By definition, the valve authority is given by the ratio Δp (valve open) to Δp (valve closed). Thus:

$$ß' = \frac{\Delta pV}{\Delta pDC} = \frac{\Delta pV}{\Delta pV + \Delta pG}$$

This authority is equal to 0.5 or more if ΔpV > or = ΔpG. This means that the pressure loss across the three-way valve must be at least equal to the pressure loss in the variable flow circuit G, including the pipes.

The circuit below gives a constant flow in the production unit and the three-way valve authority is close to 1.



A bypass AB and a primary pump can give a constant production flow and a three-way valve authority close to 1.

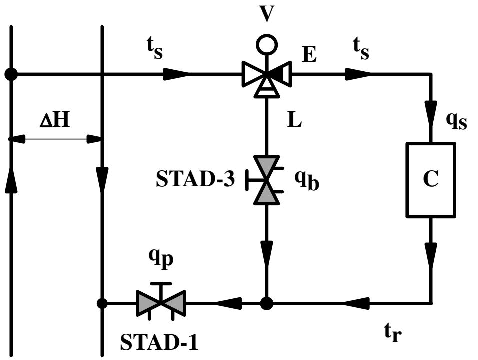
In fact, the three-way valve draws from and discharges into the bypass AB which actually forms a virtual production unit with no pressure loss. In this case the authority of the three-way valve is:

$$ß' = \frac{\Delta pV}{\Delta pV + \Delta pDBAE}$$

Since ΔpDBAE is low, the authority of the control valve is close to 1.

B.2 In diverting function

When used in diverting function, a three-way valve can supply a circuit at variable flow and constant water supply temperature while keeping the primary flow practically constant.



Diverting valve mounted in a diverting circuit.

The primary flow is transferred through port E or bypassed through port L. In principle, it's constant. The balancing valve STAD-1 located in the constant-flow pipe, limits the flow by creating a constant pressure loss.

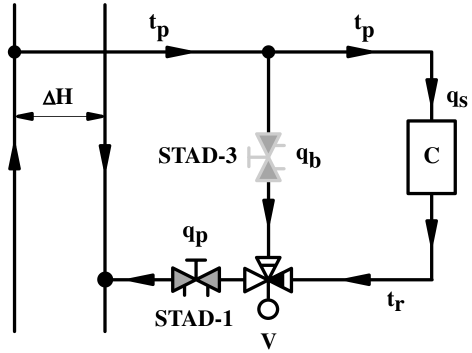
Since the three-way valve in a distribution circuit is used to keep the primary flow constant to avoid interactivity between circuits, it would be logical to take whatever action is necessary to ensure that this purpose is actually satisfied.

This is done by placing a balancing valve STAD-3 in the bypass in order to create a pressure drop equivalent to that of C for the same flow. In this way, the primary flow is unchanged if port E or port L is fully open since the hydraulic resistances in series with these ports have the same value.

The most important balancing valve is this STAD-1. STAD-3 can be omitted if ΔpC is lower than 0.25 times ΔH.

Note:

Three-way valves are usually designed to perform a mixing function: two inputs and one output. Their use in diverting function with one input and two outputs will generate water circulation through the valve in the direction opposite to the planned. For some valves, this reversal may lead to a significant increase in the noise level and a valve chattering phenomenon.



Diverting circuit using a three way mixing valve

This is why a diverting function with a three-way mixing valve is obtained by placing the valve in the return circuit as shown in the figure. This then provides the same function, while respecting the water circulation direction through the valve.

In both cases the valve authority is:

$$ß' = \frac{\Delta pV}{\Delta pV + \Delta pC}$$

To obtain an authority of at least 0.5, the pressure loss in the three-way valve must be equal to or greater than the pressure loss in the terminal unit C.

Appendix C

How to set the BPV to ensure the minimum pump flow

In some cases a BPV modulating relief valve is installed to ensure a minimum flow to protect the pump, as in the figure.

If this minimum flow is for instance 10% of design flow, the pressure loss in the balancing valve STAD-2 is only 1% of the pressure loss at design flow. Normally, this is a far too low value to allow precise measurement. So how can we measure such a small flow as qsmin?

The following method can be used:

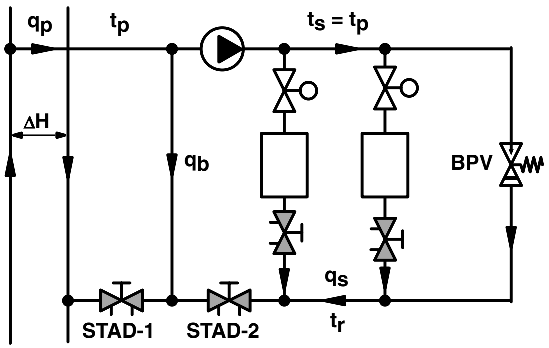
a) Find out which handwheel setting of STAD-2 that will create 3 kPa for the minimum pump flow qsmin, for instance 10% of design flow. Use the CBI, or a TA nomogram, to find the correct setting.

b) Adjust STAD-2 to this setting temporarily. Close the two-way control valves.

c) Open the BPV slowly until you obtain the minimum pump flow qsmin in STAD-2.

d) Reopen STAD-2 to its preset position.

When the coil control valves close and the flow qs goes below the specified minimum flow qsmin, the BPV opens. The BPV then bypasses a flow qsmin for as long as the flow qs in the coil control valves remains below qsmin.



This method is only applicable if the flow measurement device is of the variable orifice type, as the STAD balancing valve.

Appendix D

Definitions

Authority: See Appendix A two-way valves and Appendix B three-way valves in this manual.

Automatic: Anything that executes specific operations without human intervention.

Balancing: Measurement and control process to obtain the required flows in hydraulic circuits.

Circuit: A number of hydraulic components connected by piping forming a continuous and closed path through which a fluid, normally transporting energy, can circulate.

Compatibility: Two circuits are hydraulically compatible if water flows in each circuit are matched to obtain the required temperatures.

Control loop: A closed loop including a sensor, controller, actuator and a controlled system, in order to keep the controlled physical variable at a set value.

Design value: The plant is calculated in certains conditions with specific values for the controlled variables, outdoor conditions, supply and return water temperatures. Those values, used to calculate the plant, are the design values; they are identified by a subscript “c” (values used for calculations).

Differential pressure: The pressure difference measured between two points.

EQM: Equal percentage valve characteristic modified to avoid discontinuity of flow near the shut position.

Indoor climate: The indoor climate in a room is defined by a set of physical variables (ambient temperature, radiating surface temperatures, circulating air speeds, relative humidity) which in combination give a sensation of comfort or discomfort.

Instability: A control loop is said to be unstable if the controlled variable permanently oscillates without finding an equilibrium position. Except at extreme loads (zero or maximum), an On-Off controller is essentially unstable.

Interactivity: Two circuits are said to be interactive when variation of the water flow in one modifies the water flow in the other.

Interface: The point at which two circuits meet, and where there is generally an energy exchange. The two circuits are generally distinguished by calling one the primary circuit and the other the secondary circuit. In principle, energy is transferred from the primary circuit to the secondary circuit under normal operating conditions.

Pressure drop: The loss of pressure determined by friction in pipes or in any other element through which a fluid circulates.

Pump head: Differential pressure generated by a pump and applied to a circuit to create a forced circulation of water or another fluid. It is normally expressed as a head of liquid.

Relief valve: An automatic pressure relieving valve that opens in proportion to the increase in pressure over the setpoint. It may perform one, two or three of the following functions: (1) stabilize the differential pressure across the control valves, (2) ensure a minimum flow to protect the pump, and (3) limits the temperature drop or rise in the pipes.

Set value: Used in a control loop and selected, normally by the User, to achieve a given purpose. The controller is required to maintain this physical variable as close as possible to the set value, despite the various disturbances which may influence the controlled system.

Temperature drop or rise: The difference in fluid temperature, measurable between the supply pipe and the return pipe for a terminal or for a production unit, or more generally any temperature difference between two points in the plant.

Terminal (terminal unit): Any device which directly or indirectly transmits heat or cold into a room (radiator, heating or cooling coil).

Total balancing: A general concept designed to produce optimum indoor climatic conditions by applying a dynamic procedure to the hydraulics, which is one of the optimization factors; this procedure includes five steps:
1. Make sure that the control concept is compatible with the hydraulic design.
2. Choose suitable controllers and control valves with correct characteristics.
3. Make sure that control valves always operate under reasonable working conditions.
4. Obtain required flows in terminal units under design conditions and potentially at least these flows under other conditions.
5. Guarantee flow compatibility at all interfaces.

Total pressure: Sum of the static pressure and the dynamic pressure at the point considered.

Valve characteristic: This is the relation set up between the water flow through the valve and the valve lift, assuming that the differential pressure across the valve remains constant. The flow and the lift are expressed as a percent of their maximum value.