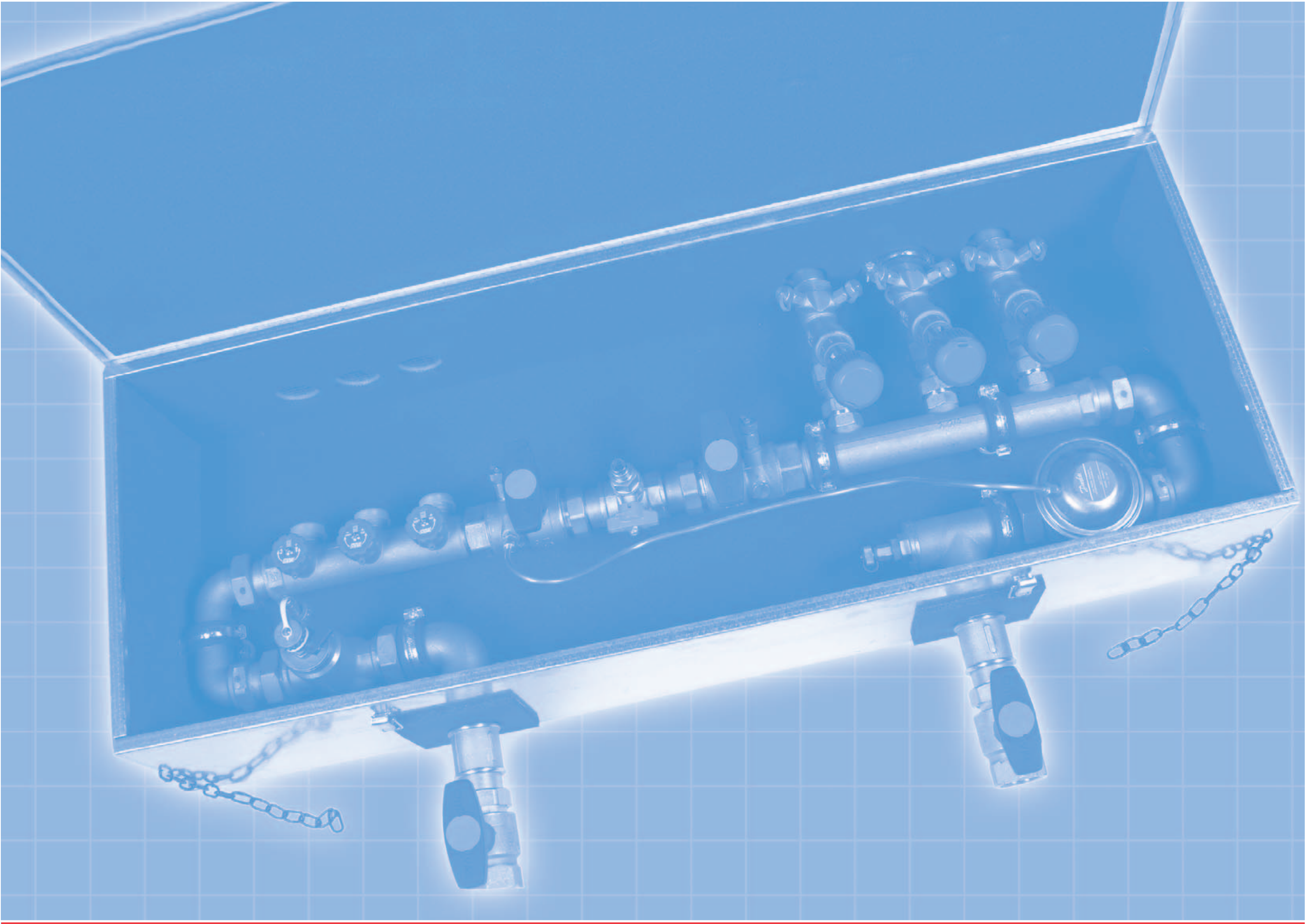

DESIGN GUIDE - JUNE 2008

Variable Flow Systems &

FloCon™ Commissioning Modules

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S·A·V MODULES

CONTENTS

1. INTRODUCTION

This guide sets out a methodology for designing a pipework system with variable speed pumps and incorporating SAV products such as differential pressure control valves (DPCVs), pressure independent control valves (PICVs) and commissioning modules. The guidance given is applicable to re-circulating secondary heating and chilled water systems serving terminal units such as radiators, fan coil units, or chilled beams.

The topics covered in this guide include:

- Calculation of pump energy savings
- DPCVs
- Control of pump speed
- Sizing two port control valves
- Variable speed pump selection
- Location and sizing of pressure relief valves

Design options covered:

- DPCVs on main branches
- PICVs on terminal branches
- Commissioning modules with integrated DPCVs serving groups of terminals

2. BENEFITS OF VARIABLE VOLUME PUMPING SYSTEMS

The main benefits of variable speed pumping are as follows:

- Pump energy savings
- Capital cost savings
- Reduced chilled water pump heat gains
- Reduced thermal losses from pipes
-

These benefits are described in more detail in the following sections 2.1 to 2.4.

2.1 PUMP ENERGY SAVINGS

For most heating or chilled water systems in the UK, the requirement for heating or cooling output will probably be at its peak for less than 10% of the time. For the remaining 90% of the time, the demand will be significantly reduced. During these periods there is potential to pump less water thereby reducing the annual pump energy consumption.

In order to properly quantify the energy saving, the system resistance must be calculated at full and minimum load conditions and plotted relative to the pump curve, as shown in Figure 1. The energy saving achievable will be equal to:

$$\Delta p_1 Q_1/\eta_1 - \Delta p_2 Q_2/\eta_2$$

Where,
Δp = pressure (Pa)
Q = flow rate (m^3/s)
η = pump efficiency

If both pressure and flow rate are permitted to fall together, a significant energy saving is achievable. If the pump pressure reduces by half and the flow rate reduces to one quarter then the pump energy consumption will reduce to approximately one eighth of its peak value.

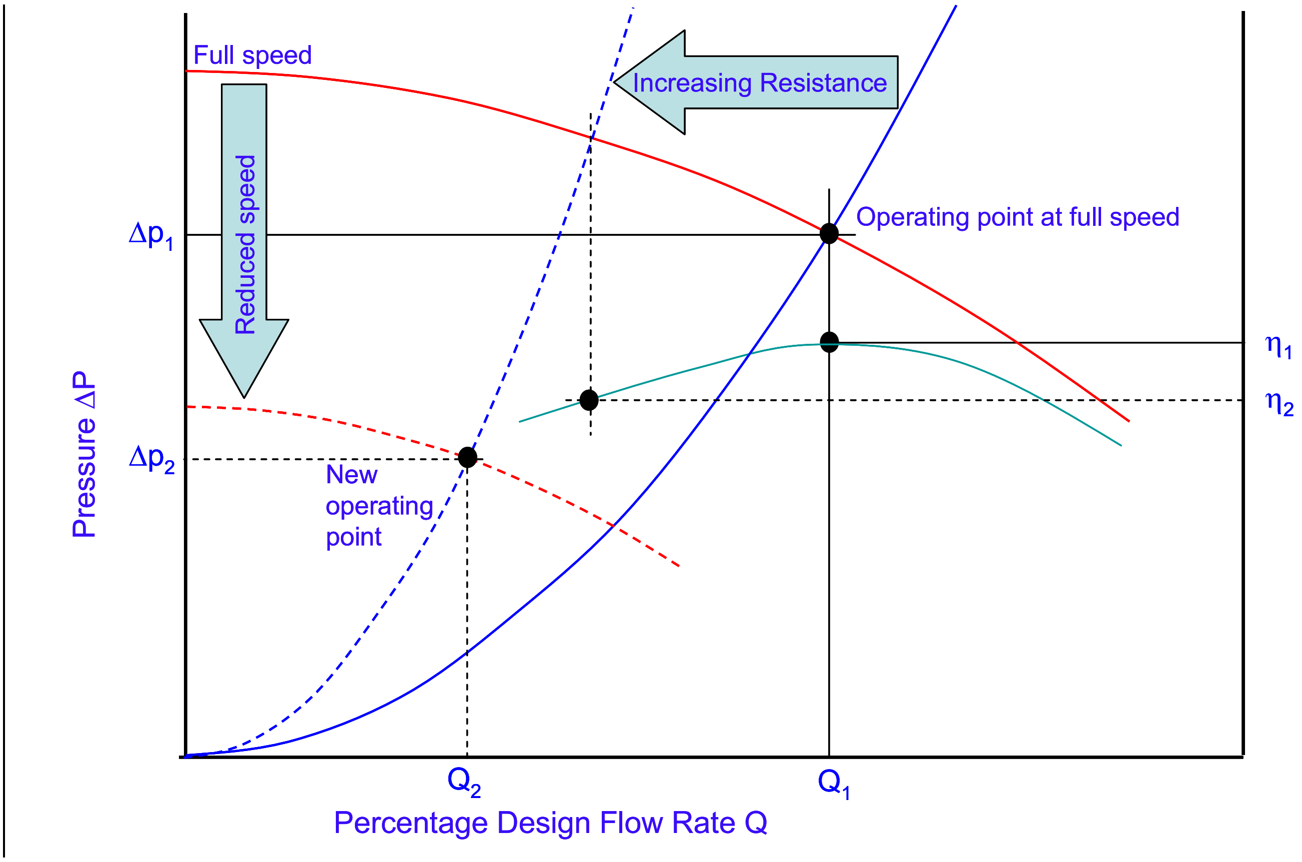

Figure 1: Potential change in pump operating point as system resistance increases

2.2 CAPITAL COST SAVING – DISTRIBUTION PIPE WORK

Where it is predicted that there will never be simultaneous maximum demand in all parts of the system, some allowance for diversity can be allowed. Pipework close to the pump can be sized based on the estimated peak simultaneous demand rather than the maximum possible demand. For the same reason a reduction in pump size is also possible.

2.3 REDUCED CHILLED WATER PUMP GAINS

Because a proportion the pump energy is transferred to the circulating water as heat, in a chilled water system this extra heat consequently has to be removed by the chillers. By reducing pump energy consumption at light loads, the extra cooling load to the chillers is also reduced.

2.3 REDUCED THERMAL LOSSES FROM PIPEWORK

In a variable flow system, return water from heating circuits tends to come back at a lower temperature than in a constant flow system. Similarly return water from cooling circuits tends to come back at a higher temperature than in a constant flow system. As a result, the thermal losses or gains from pipework are reduced resulting in greater overall system efficiency.

3. DIFFERENTIAL PRESSURE CONTROL VALVES (DPCVS)

The main purpose of a DPCV within a variable flow system is to minimise the amount of pressure against which downstream 2 port valves need to close. The pressure differentials across 2 port control valves need to be kept as low as possible in order to maximise their modulating control authority and minimise the risk of valve noise or erosion.

Figure 2 shows the basic design for a DPCV. The valve will control pressure constant between points A and B, i.e. across a variable resistance 2 port control valve (or multiple 2 port valves).

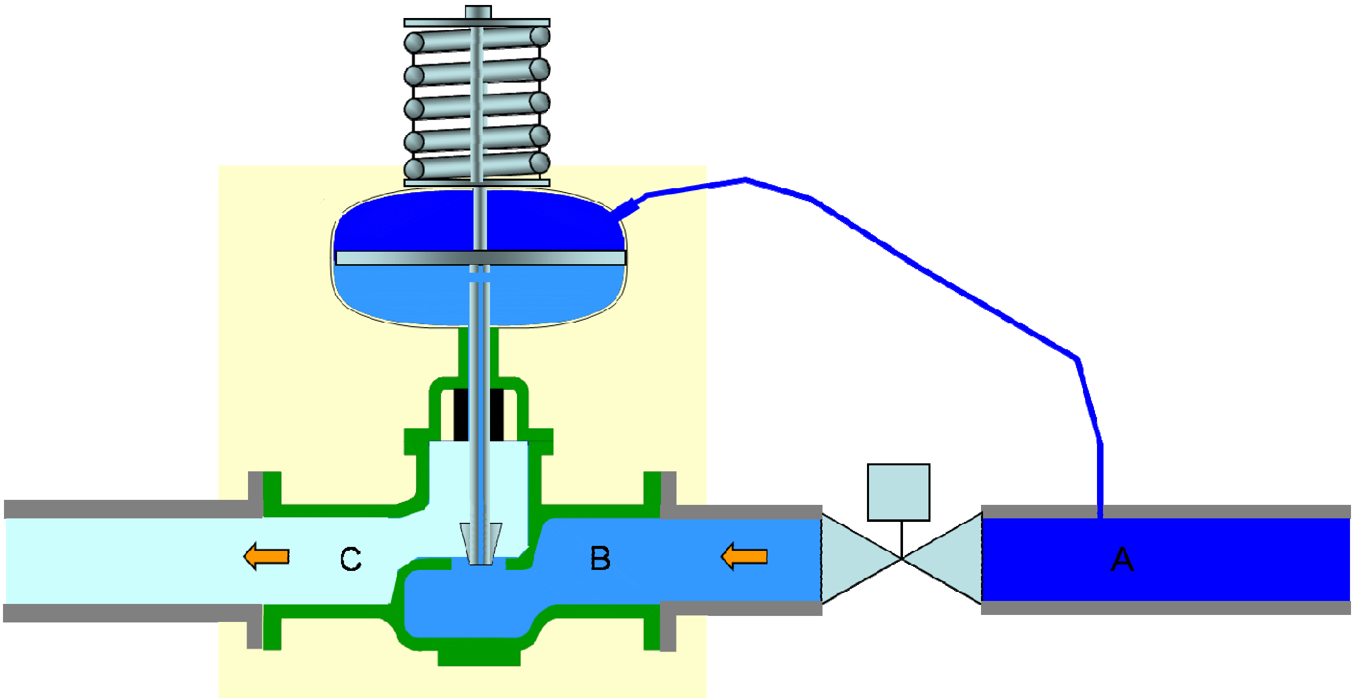

Figure 2: Cross section of differential pressure control valve

The disk shaped housing at the top of the valve contains a rubber diaphragm. A capillary tube from the flow pipe is connected to the upper side of the diaphragm whilst the lower side is exposed to pressure from the return pipe. Once the valve is set, any variation in pressure between the flow and return pipes will be registered causing the diaphragm to flex resulting in movement of the valve stem.

It can be seen that if the 2 port control valve begins to close the pressure at A will increase causing the DPCV to close as well. Hence, the DPCV reduces the amount of pressure against which the 2 port valve needs to close.

To work effectively, DPCVs require a minimum differential pressure across them – typically 10-20kPa.

DPCVs also act to compensate for valve closures taking place in other parts of the system. If overall pressure across the branch i.e. between points A and C in Figure 2 should increase, then the DPCV pressure valve will detect this and throttle itself to take out the excess pressure. Similarly, if the pressure available should reduce, then the DPCV will open so that there is no reduction in flow rate.

4. CONTROLLING PUMP SPEED

The simplest method is to vary pump speed such that the pressure differential between two points in the system is held constant. A differential pressure sensor can be installed to monitor the differential pressure between these two points and the value fed back to the pump controller.

The question arises: where best to locate the differential pressure sensor?

It can be seen from Figure 1 that energy savings are maximised when both the pump flow rate and pressure differential are reduced by as much as possible. For this reason, holding pump pressure constant is a poor solution and should be avoided. Although this is usually the simplest solution (pumps often come with their own constant pressure control) the energy savings will be poor. This is because by holding pump pressure constant the pump efficiency falls dramatically thereby negating the potential energy saving. The pump efficiency is poor because by maintaining the pressure constant, the heat generated by the pump increases, and more strain is imposed on the pump motor bearings.

A much better solution is to install a differential pressure sensor at a more remote location in the system. Most systems will rely on the operation of DPCVs to protect 2 port control valves. As stated above, DPCVs require a minimum differential pressure across them to function properly. Therefore, the best location for a differential pressure sensor controlling pump speed is across the most remote DPCV controlled pipe sub-branch (i.e. the index branch).

By ensuring that pump speed is controlled such that there is always enough pressure across the most remote branch should usually ensure that upstream branches also have enough pressure. However, in large systems this will not always be true. For example, if all of the 2 port control valves on the index branch should close, then the next branch nearer to the pump becomes the index.

Hence for large systems, multiple differential pressure sensors should be located at system extremities. Modern BMS systems and variable speed drives have the ability to monitor a number of sensors detecting which of them indicates the lowest pressure and controlling pump speed such that a specified minimum pressure is always maintained across all sensor locations.

5. SIZING TWO PORT CONTROL VALVES

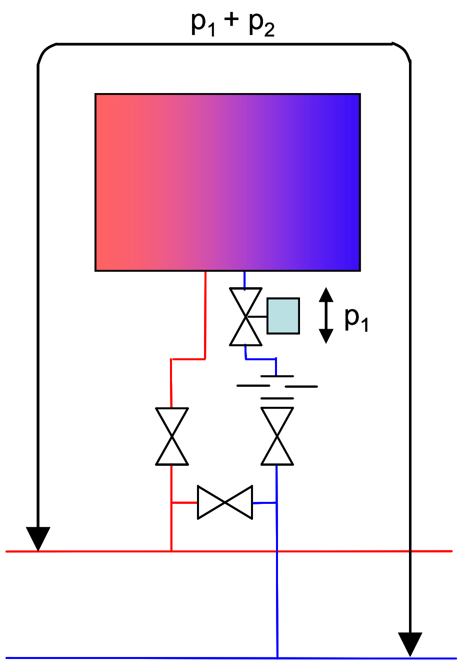

Figure 3: Sizing 2 port valves

In order to achieve good modulating control, two port control valves need to be sized such that the pressure drop across them when fully open is a significant proportion of the overall pressure drop in the circuit being controlled. The ratio of control valve pressure drop versus total circuit pressure drop i.e. (p_1 / (p_1 + p_2) in Figure 3), is referred to as “valve authority”.

Note that the pressure losses p_1 and p_2 can be determined at their design flow rates. It makes no difference if the overall pressure $p_1 + p_2$ is expected to increase or decrease at part load. Any change in the overall pressure $p_1 + p_2$ will have a proportionally equal impact on p_1 and p_2 meaning that the valve’s authority will remain the same.

However, if the branch pressure does increase significantly under part load conditions, the result will be an excess flow through it. Then as the control valve closes, the first part of its travel will be used up in returning the flow back to its design value. Although the valve will have good authority it will behave as if it has poor authority.

A DPCV located upstream of the control valve helps to minimise any increase in pressure across the valve. The closer the DPCV is to the control valve, the better it will be able to protect the valve and the better performance the control valve will give.

In traditional constant flow circuits, the normal advice was to aim for a valve authority of 0.5. This is relatively easy to achieve since in a constant flow system the circuit being controlled is usually that governing the by-pass around a terminal unit. This meant that if the 3 or 4 port valve had a pressure drop similar to that of the terminal unit, the required authority was achieved.

However, for a system with 2 port valves, the circuit pressure losses may be much higher since they include branch pipes and balancing valves. Since achieving a control valve authority of 0.5 in such a system usually results in an enormous increase in overall system pressure loss, a more pragmatic approach has had to be adopted. Control valve authorities of 0.2 are generally considered acceptable for small load heating coils (i.e. <1.5kW). For larger heating coils and cooling coils, a minimum of 0.3 should be achieved.

6. PUMP SELECTION

The pump must be selected such that it is able to deliver the peak design water flow rate against the design pressure drop around the circuit with greatest resistance, commonly known as the index circuit. It is also essential to calculate the minimum load operating point so that the overall pump energy saving can be quantified.

In order to ensure that the variable pump speed is responsive to changes in system pressure, it is important to select the pump such that the full load operating point of the pump is in a central region of the pump curve. If the system characteristic intersects the pump characteristic at a flat or steep region of the pump curve, then variations in system resistance will cause only small changes in pressure at the pump. The pump speed controller may not be able to respond effectively to such small changes in pressure. For this reason it is important not to over-size pumps by adding excessive margins to pipe pressure loss calculations.

Pump speed controllers must be selected to suit the proposed method of control. Controllers are available which enable multiple remote differential pressure sensors to be monitored and, if necessary, each can be given their own set point. Alternatively this function can also be achieved from a central BMS.

In order to monitor, and if necessary adjust the pump speed control, the pump variable speed drive should ideally be wired back to a BMS. Furthermore a manual override should be provided so that for commissioning and test purposes, the pump speed can be varied to any required value.

Additional energy savings can be achieved by turning off the pump completely once all of the 2 port control valves are closed. This can be achieved by polling the 2 port control valves via the BMS system. When all of the valves signal they are closed, the pump can be switched off.

7. SYSTEM BY-PASS

As 2 port control valves close, the differential pressure control valves in the system will also begin to close as they attempt to retain the same controlled pressure differential at a reduced flow rate. Potentially, if all 2 port control valves close, the pump will end up pumping against a closed system potentially resulting in pump overheating.

For this reason, some path must always be left open to flow. The minimum turndown ratio for a given pump will depend on how much heat it generates at very low flow. If pump pressure is maintained constant, then unnecessary heat will be generated thereby restricting the extent to which pump speed can be reduced. If pump pressure is allowed to fall at part load, as recommended above, then a greater reduction in pump speed is possible.

In general, an overall reduction to 20% of the pump's full flow is usually acceptable. This achieves the majority of the potential energy saving without the risk of over-heating the pump motor.

One way to maintain this minimum flow is to install 4 port control valves on intermittent terminal units throughout the system. A 4 port control valve differs from a 2 port valve in that it diverts flow through an internal by-pass rather than throttling the flow completely. Hence, a 4 port valve located on every fifth terminal unit should achieve approximately 20% by-pass when all control valves are in their closed positions. By installing 4 port control valves on terminal units at system extremities, this will ensure that hot/chilled water is always available in the pipe straight away, and water treatment chemicals are always circulated thereby avoiding temporary dead-legs.

An alternative way to maintain minimum flow is to install pressure relief valves. Pressure relief valves operate by detecting the pressure differential across them and opening only when a pre-set differential pressure is exceeded. This type of pressure relief valve is also referred to as a "reverse acting differential pressure control valve", or an "auto-bypass valve".

The simplest method to maintain a minimum flow is to install fixed resistance by-passes that are always open to flow i.e. with no form of flow control whatsoever. This solution is particularly applicable to commissioning module applications (as described in section 8.3) as they can be easily sized and integrated within the modules.

8. DESIGN OPTIONS

The main options for system design are as follows:

- DPCVs on main branches
- PICVs on terminal branches
- Commissioning modules with integrated DPCVs serving groups of terminals

The following sections 8.1 to 8.3 describe these options.

8.1 DPCVs ON SUB- BRANCHES

The design of systems using DPCVs on sub-branches is described in CIBSE Knowledge series Guide KS7 "Variable flow pipework systems".

Individual sub-branches serving groups of terminal units are provided with a DPCV which controls and limits the total pressure differential across the sub-branch. A typical system schematic is shown in Figure 6.

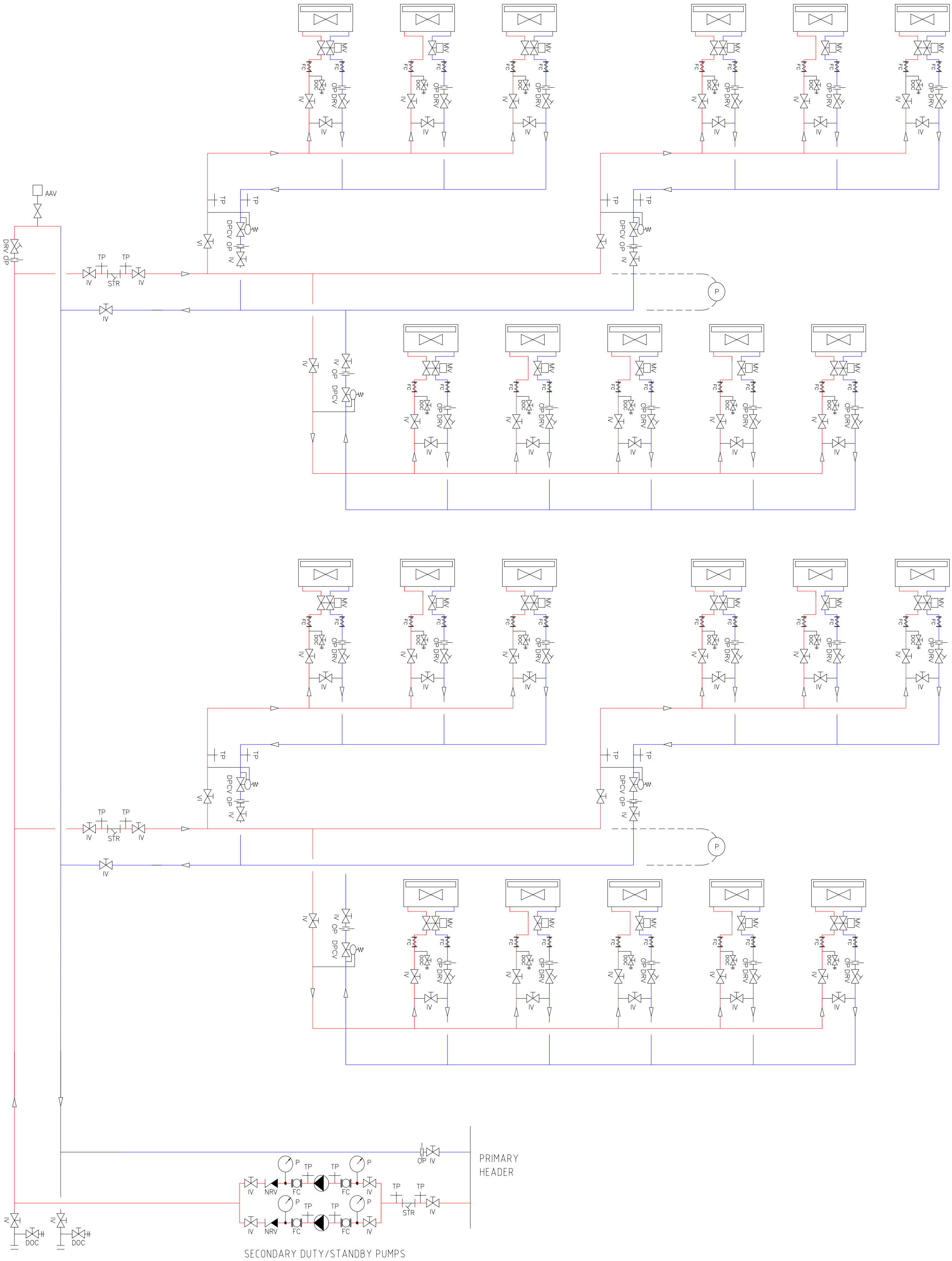

Figure 6: System with DPCVs on sub-branches

By locating the DPCV at these locations, two port control valves will only need to control and shut off against the branch design pressure rather than the full pump pressure, as might be the case if the valve were omitted.

Each 2 port control valve must be sized individually, since the pressure available across each terminal branch will vary. Those branches close to the DPCV will have larger pressure losses across them than those further away. For this reason, the sizing of control valves cannot be done by the controls supplier or the terminal unit supplier. Each valve has to be sized against the available branch pressure differential and only the design engineer can calculate this value.

The location of DPCVs on long sub-branches (for which the pressure controlled constant by the DPCV is greater than 50kPa) sometimes makes it difficult select 2 port control valves with effective modulating control. Most manufacturers of 2 port control valves supply valves in a fixed range of kv values. At low flows it can sometimes be difficult to achieve good authority (as defined in section 5 above) using standard valves. For this reason, branches protected by DPCVs should be limited in size. As a rule of thumb, branches protected by an upstream DPCV should serve no more than 12 terminal units.

Pressure tappings should be located across each DPCV controlled circuit so that the pressure controlled constant by the DPCV can be checked. A flow measurement device in the same circuit will also be required to facilitate setting of the DPCV. In order to flush through the DPCV during the pre-commission cleaning stage, sufficient low resistance by-passes need to be incorporated within the system. When these are opened and system flow rate increases, this should also enable the DPCV to open fully. Small bore flushing by-passes across terminal units may not be sufficient for this purpose.

8.2 PRESSURE INDEPENDENT CONTROL VALVES (PICVs)

PICVs are able to combine the functions of regulating valve, DPCV and two port control valve in one body. They can be fitted on all terminal units thereby avoiding the need for separate flow regulating valves or DPCVs upstream of them.

A typical example is shown in Figure 7.

It can be seen that the upper part of the valve is effectively a two port control valve which can also be used for flow regulation. The bottom part of the valve is a DPCV which holds the pressure differential constant across the two port valve above.

To achieve a flow balance the position of the valve spindle can be adjusted until the required flow is achieved. Because there is always a constant differential pressure across the two port valve, the setting of flow rate is straight forward and does not require a separate flow measurement device. This is because the flow rate through a known opening size with constant pressure differential can be predicted in advance. Therefore, a scale setting on the valve is all that is required to set flow rate.

Once the valve has been set in the required position to give the correct flow rate, the valve actuator can be fitted. This will drive the valve closed and open from its set position in response to room load requirements. Because the built in DPCV holds the pressure loss across the two port valve constant, the valve authority achieved is always equal to 1. This means that very good authority will be retained under all pressure conditions. The movement of valves elsewhere in the system or changes in pump speed will not affect this.

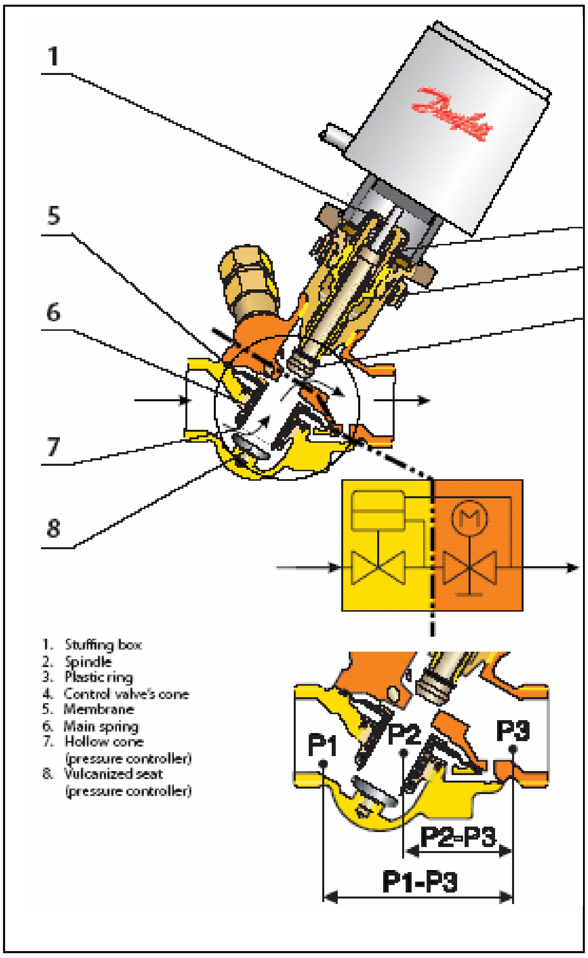

Figure 7: Pressure independent control valve (PICV)

In order to control accurately, each DPCV must be sized such that it has a minimum pressure drop of 7-14kPa across it. Without this it would not be able to maintain accurate control of the pressure differential across the two port valve. Furthermore, for the smaller valves, there will be an upper limit on the pressure they can remove from the system without noise. Maximum differential pressures of up to 450kPa are achievable. Measuring nipples are provided to enable the commissioning specialist to establish whether the valve is operating within its required pressure range.

Approximately 30 small 15-20mm combination valves can be purchased for the cost of one large 50-65mm DPCV. On sub-branches with more than 30 terminal units, they will therefore be more expensive than a single DPCV. However, they will give better control and ease of commissioning for the reasons stated above.

Combination valves can either be installed on terminal units with traditional by-pass arrangements upstream or within Commissioning Modules.

8.3 SAV FLOCON COMMISSIONING MODULES

SAV Commissioning Modules are mini-headers that distribute flow from a central valve manifold arrangement to 2-6 terminal units. Modules are designed, pre-fabricated and pressure tested off-site resulting in significant savings in site installation time and cost. A study carried out by BSRIA found that compared to a traditionally designed fan coil unit the normal activity times were reduced by the following amounts:

- For installation, a 22% time saving
- To have its main pipework flushed, a 57% time saving
- To have its terminals flushed a 77% time saving
- To be flow balanced a 56% time saving

SAV Commissioning Modules can either incorporate combination valves or a single header DPCV. For three or more terminal units a single header DPCV is more cost effective than several combination valves.

The DP-CS Module layout is as shown in Figure 8. The features indicated are as follows:

1. A large bore strainer which can remove particles down to 0.6mm in size.

2. A flow manifold with in-built isolating valves on each port.

3. Flexible multi-layer pipe (i.e. plastic coated metal pipe) runs out to terminal units.

4. A central flushing by-pass arrangement with in-built flushing drain for forward and back-flushing through terminal units plus manual air vent.

   (*Also with the potential to incorporate an optional fixed constant flow by-pass enabling flow through the pump to be maintained during total closure of downstream 2 port control valves*).

5. A return manifold with close coupled commissioning sets (double regulating valves and flow measurement devices).

6. A spacer piece permitting the subsequent installation of an energy meter for the purpose of sub-metering energy consumption for building regulations compliance of tenant billing purposes.

7. A differential pressure control valve pre-set to hold the pressure differential between flow and return manifolds constant.

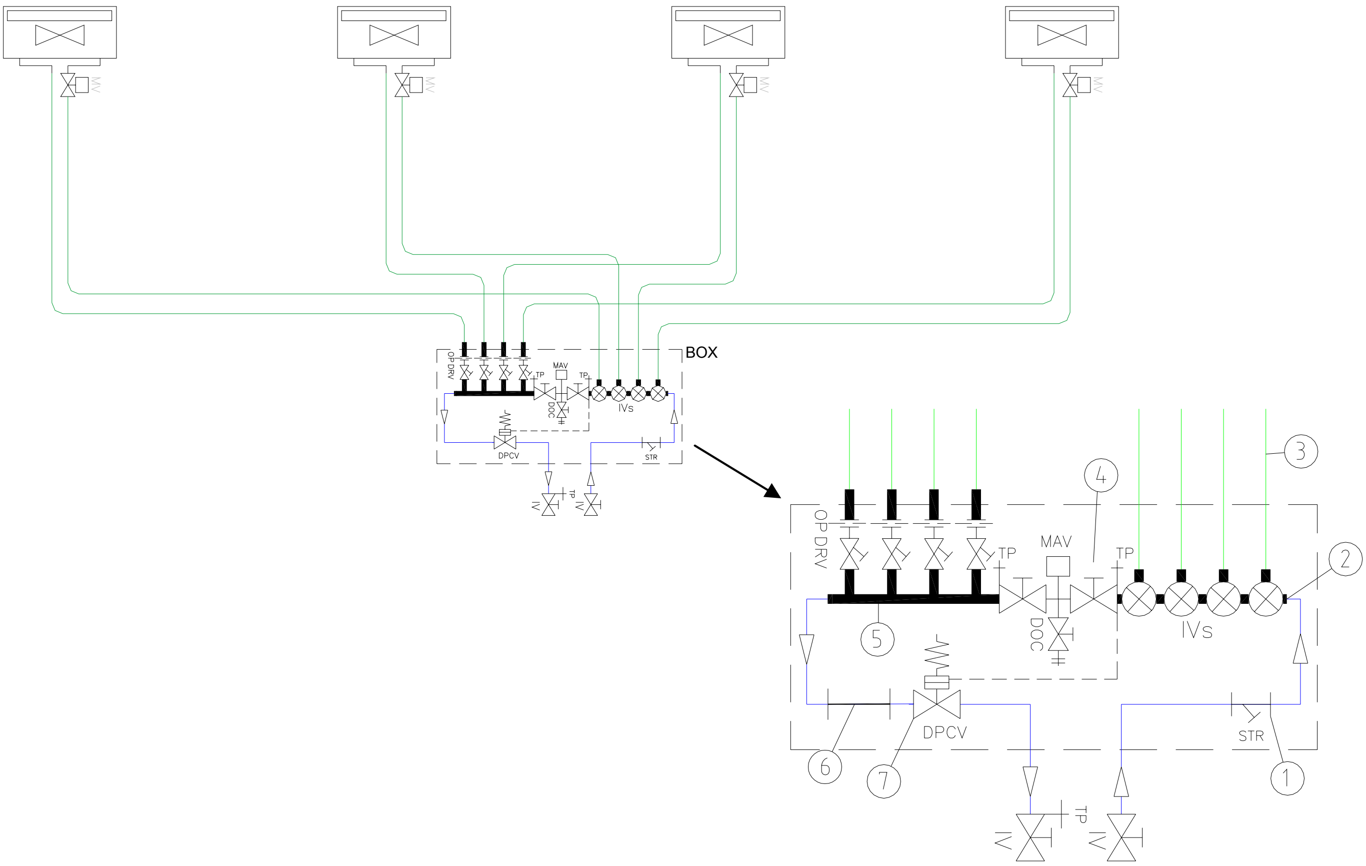

Figure 8: Schematic diagram of DP-CS Type Commissioning Module

Given details of the flow rates and pressure losses through the terminal units they will serve, and approximate details on their proposed location, SAV can size all components that make up the controlled circuits including manifolds, DPCVs, commissioning sets, multi-layer pipe and 2 port control valves.

To avoid the risk of selected 2 port valves being installed on the wrong terminal units, an alternative option is to allow SAV to pre-install them on manifold flow ports. This would mean that all terminal unit valves are located safely within the module. The control wiring can then also be centralised at the module.

DPCVs

The function of the DPCV in a Commissioning Module is to maintain a constant differential pressure between flow and return manifolds thereby protecting circuit flow rates regardless of changes in the available pressure upstream and regardless of the effect of control valve movements in circuits fed from the manifolds.

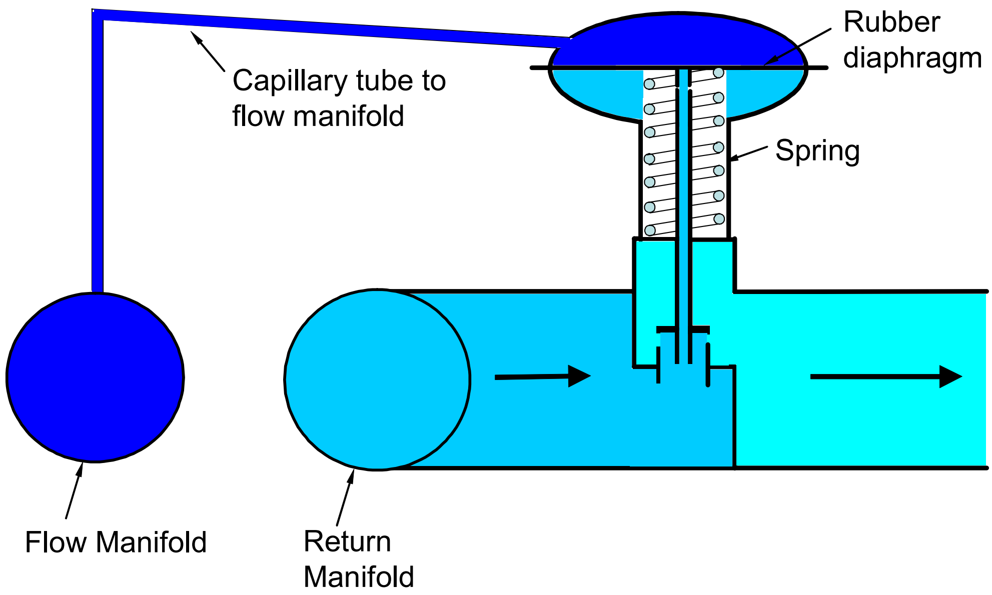

Figure 9: Cross section of differential pressure control valve

The DPCVs used in the Commissioning Module are pre-set to control at fixed differential pressure settings. The pressure settings available are 20kPa, 30kPa, 50kPa and 70kPa. The setting of a particular valve can easily be changed between these values simply by changing the internal spring within the valve, although if sized correctly, this should not be necessary.

In order to control accurately, each DPCV must be sized such that it can achieve some degree of control authority across the circuits it is controlling. Therefore the valve itself typically requires a minimum pressure drop of 10-15kPa across it. Without this it would not be able to maintain accurate control of the pressure differential between the manifolds.

Hence, if a valve is selected with a differential pressure setting of 20kPa, then the pressure drop required across the entire Commissioning Module is likely to be 30-35kPa. Similarly if the valve is selected to control 30kPa, then the pressure drop across the entire Commissioning Module is likely to be 40-45kPa etc.

The DPCVs in the Commissioning Module are designed to control against a pressure differential of up to 12bar without noise. This means that even if the full pump pressure were imposed across the DPCV, provided this was not greater than 12bar, the valve would continue to function.

The DPCVs used in Commissioning Modules range in size from 15-32mm.

Two Port Control Valves

In the case of the Commissioning Module, all two port control valves are sized against the pressure differential controlled across the manifolds by the DPCV. Due to their proximity to the DPCV, there is no risk of excess flows occurring as two port valves begin to close.

Figure 10 illustrates the principle. The control valve authority is equal to the ratio

$\Delta P_1 / (\Delta P_1 + \Delta P_2)$

where $\Delta P_1 + \Delta P_2$ is the pressure differential between the manifolds held constant by the DPCV.

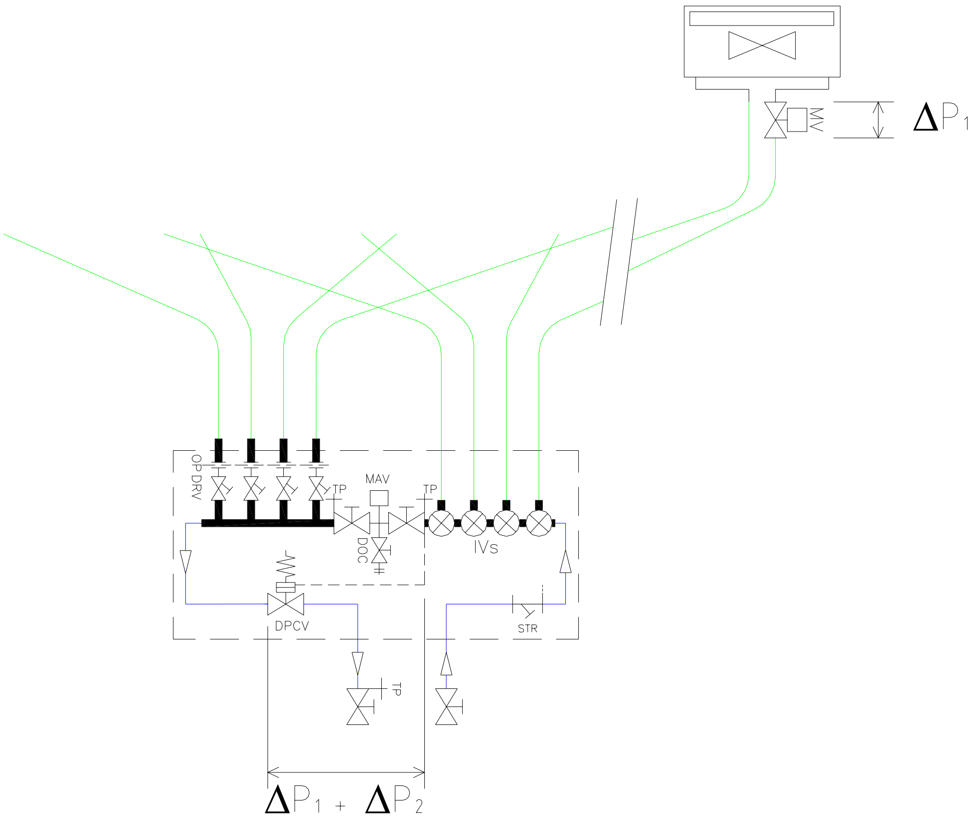

Figure 10: Calculation of control valve authority in Commissioning Module application

From experience, control valve authorities of 0.3 - 0.7 are regularly achievable using Commissioning Modules, with authorities below this only becoming necessary when either the specified flow rate is very low (and it becomes impossible to generate any significant pressure drop across commercially available 2 port valves) or the design flow rate is very high and the resulting pressure drop approaches the maximum capacity of the DPCV.

In virtually all situations, however, control authorities greater than 0.20 are usually achievable.

Commissioning

The Commissioning Sets on the return manifold are there in order to achieve a flow balance when all control valves are fully open and calling for full flow. Without them, the flows to each of the terminals would vary depending on their respective resistances. This could result in some circuits being starved of flow during periods of peak load.

The valves are individually sized (in accordance with CIBSE and BSRIA requirements) such that the flow measurement device can generate a pressure drop signal greater than 1kPa at the design flow rate, and the valve can take out the required pressure imbalance without having to be closed beyond its 25% open position.

The flow balancing procedure in this application is greatly simplified compared to that for a traditional constant flow system. In a constant flow system one of the circuits off the branch would be the index circuit. This is the circuit that, with all valves fully open, receives the lowest percentage of its design flow rate. As such, the commissioning valve on this circuit would be left fully open, and the valves in other circuits would be progressively closed until their percentage design flow rates matched that in the index.

However, in the Commissioning Module arrangement, individual commissioning valves are not being used to balance flows in the same way. Their function is, instead, to remove any excess pressure imposed by the DPCV.

For example, if the DPCV is set to control at 30kPa but a circuit only requires a design pressure loss of 25kPa, then the commissioning valve will be required to take out the remaining 5kPa. Since it is unlikely that any circuit design pressure loss will exactly match the DPCV setting, all of the commissioning valves are likely to be regulated to some extent. There will be no fully open index as in a constant flow system.

Furthermore, the procedure for proportional balancing will not apply. As each commissioning valve is adjusted, the DPCV will also adjust itself so that the pressure differential between the manifolds returns to its set value. Therefore once the flow to one circuit is set, adjusting the valve on the port next to it will have no influence on the valve already set. There is therefore no need to constantly refer back to the flow at the index as in a constant flow system.

The use of Commissioning Modules with integral DPCVs means that there is no need to install commissioning valves upstream of the Commissioning Modules. This is due to that fact that the DPCVs will compensate for any variations in system pressure occurring anywhere else in the system. Once set, the flows to and from a particular Commissioning Module will be unaffected by any works occurring elsewhere in the system. This means that all valve adjustment will take place at the Commissioning Modules. It also means that areas of a building can be handed over in stages.

The Commissioning Module also provides an excellent diagnostic tool for identifying and resolving flow problems. The pressure drop around each terminal unit circuit can be measured using the pressure test points on the flow and return manifolds. This means that it is easy to establish whether terminal unit and 2 port valve pressure losses are in accordance with their design values. Furthermore the pressure available across the entire Module can be measured. This can be used to confirm whether sufficient pressure is available from the pump to enable the DPCV to control accurately.

Multi-Layer Pipes

Multi-layer pipes (i.e. plastic coated metal pipes) come in a larger variety of sizes than traditional copper or steel pipes. It is therefore possible to select pipes which are better matched to the circuit flow rates. In particular very low flows can be put through smaller pipes so that reasonable velocities are maintained which will help move air pockets and dirt.

In the case of the Commissioning Module, the choice of pipe size can also help to balance pressure drops around circuits. Where required, circuits can be given extra resistance simply by selecting smaller pipes.

Furthermore, if the overall pressure drop around manifolds, valves and terminal units are approaching the setting for the DPCV, then selecting a larger pipe size to reduce the pressure drop in the pipework can sometimes help to bring the overall loss back within the limit of the DPCV.

Final sizing of pipes will take into account all of these considerations.

There are two options for the jointing of multilayer pipes.

<u>Compression fittings</u> – these work in a similar way to copper compression fittings in that a compression nut squeezes a brass olive onto the outside of the pipe thereby gripping it tightly. Unlike copper compression fittings, sealing is achieved separately by means of a double o-ring arrangement that is similarly compressed by the compression nut. These joints are extremely strong. Under test, the pipe itself is more likely to fail than the joint.

<u>Press-fit fitting</u> – As an alternative to compression fittings, joints can be made by press-fit. This involves squeezing a metal sleeve over the outside on the pipe and onto a specially formed sleeve. Some clients prefer this method of jointing since a small hole in the metal sleeve allows the user to see straight away whether the joint has been properly made.

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