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Article

Pressure oscillation in **district heating** installations

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Pressure oscillation in district heating installations

Danfoss has been marketing district heating pressure controller for decades, but it is only recently that we have seen an increasing number of inqueries around the question of pressure oscillation in the district heating network. This applies to the mains themselves, the distribution network, individual supply pipes and small independent district heating connections.



Danfoss has carried out an extensive analysis in this area, partly to establish the cause of the problems, and partly to find out which possibilities exist for solving them. In general, pressure oscillation can be divided into two main categories:

- Reaction oscillation
- Self-oscillation

Reaction oscillation arises where the Dp controller reacts to disturbances and amplifies them, but where there is no suggestion that the controller itself has become unstable.

Self-oscillation is a phenomenon that manifests itself when the Dp controller on which the system is based begins to oscillate regularly without the influence of external factors.

To better understand these two forms of oscillation we shall first look at three system factors. Pressure oscillation is conditional on the presence of these factors. The three system factors are:

The three system factors are:

- System elasticity in the control loop
- The control rate of the pressure controller
- The dimensions of the consumer supply pipe

System elasticity in the control loop

System elasticity must be understood as the relation between the volume of the system (water content) and the absolute system pressure (static pressure).

System elasticity depends on the quantity of air in installations or on the the elastic properties of components. Plastic tubes not cast into concrete could be involved, versus steel pipes or radiators which are more or less pliable. It is relatively easy to gain a picture of the magnitude of system elasticity for the individual installation: the main cocks are closed and then the quantity of water that has to be drained off to reduce the pressure by, for example, 1 bar, is measured. A few typical values gained from experience with correctly bled systems:

| System type | System elasticity* |
|--------------------------------------|--------------------|
| New 1-family installations (DK/S) | 30 – 50 ml/bar |
| Old 1-family installations (DK) | 50 – 100 ml/bar |

*) Heating and hot-water-service installation.

Unfortunately, these values are not completely correct seen in relation to pressure oscillation in district heating installations because they cover the whole installation (heating and hot-water-service). In an actual situation with pressure oscillation, only the system elasticity in that part of the installation affected by the pressure controller is of interest, i.e. the stretch between the pressure controller and the valves that control the heat (control valves/radiator thermostats).

However, it is difficult to measure the elasticity in this part ("radiator") of the installation alone since it is normally impossible to isolate it with the shut-off valves which form part of the system.

To be certain that no oscillation problems occur the system elasticity in the control loop must not exceed 2 – 15 ml/ bar, depending on the reaction rate of the controller and the dimensions of the consumer supply pipe.

System elasticity comes into play when consumption in the system



FIGURE 1

or from the network changes. The change in load changes the pressure losses in the network which in turn influences the absolute pressure (static pressure) in the system.

When the absolute pressure changes, the volume of the heating system must adapt to the new pressure. When the pressure rises it means that more water must flow into the system than out. And while the pressure falls, more water must flow out of the system than in.

This movement of water between the flow and return pipes creates and maintains pressure oscillation.

The control rate of the pressure controller

The task of the pressure controller is to maintain the required differential pressure between the two points in the heating system at which the impulse tubes are connected. The controller (fig. 1) controls the differential pressure in the following way:





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Together with the force from the setting spring, pressure from the return pipe (–) acts on the minus side of the controller diaphragm and thereby moves the cone towards the openvalve position, while pressure from the flow pipe (+) acts on the plus side of the same diaphragm so that the cone moves towards a closedvalve position. The cone controls the water quantity and it is in this way the controller maintains the differential pressure determined by the setting spring.

The pressure controller determines whether a large or small quantity of water is pumped into the system (when the controller is installed in the flow pipe) or whether more water or less water is confined in the system (when the controller is installed in the return pipe) so that the quantity of water necessary to give the set differential pressure is always present in the heating system.

When the flow is controlled by the pressure controller in this way, variations in flow velocity are caused with consequent pressure pulses in the supply pipes in the form of positive and negative pressure surges.

Both simulation and tests have shown that an interesting parameter of pressure surges is the rate at which the pressure controller operates (Rh). The control rate is the rate at which the controller changes its kv value for a certain variation in the differential pressure, in relation to the required differential pressure. In other words, the control rate of the controller is an expression of how fast the controller opens to allow flow or closes to shut off flow on changes in the differential pressure. In other words, the control rate of the controller is an expression of how fast the controller opens to allow flow or closes to shut off flow on changes in the differential pressure.

The control rate (Rh) is determined by the formula:

$$\mathsf{Rh} = \mathsf{Q}_1 \times \frac{\Delta \mathsf{k}_{\mathsf{v}}}{\Delta \mathsf{s}} \times \frac{1}{\mathsf{A}_{\mathsf{m}}}$$

where:

Rh = control rate in $(m^3/h)/s$ Am = controller diaphragm area in m² Dkv/Ds = control valve characteristic $(m^3/h)m$

Qi = flow through the impulse tubes for the actual deviation in differential pressure measured in m³/s

It can be seen from the parameters which determine control rate that the simplest way of damping a pressure controller is to reduce the flow in the impulse tubes by increasing the flow resistance, whereas the only way to accommodate the other parameters is to change the design of the pressure controller.

Dimensions of the consumer supply pipe

Further conditions of interest in connection with pressure oscillation are the flow velocity and the dimensions of the supply pipe. The larger the diameter of the supply pipe is in relation to the quantity of water it has to transport, the lower the flow velocity in the pipe becomes.

In district heating installations the dimensions of the consumer supply pipe are based on several criteria; heat loss, pressure drop, price and usable life being among the most important.

The chosen dimensions will therefore normally be determined as a compromise based on these parameters. This often means that the dimensions chosen for the consumer supply pipe are so small that in practice the flow velocity can become high enough to produce pressure surge.

Pressure surge is a consequence of flow velocity changes in the network. The variations in flow velocity arising from system elasticity in the control loop and the control rate of the pressure controller also occur in consumer supply pipes, but at a later point in time because of the delay in the system.

When the flow velocity varies as a consequence of demand, the flow becomes either accelerated or decelerated. Accelerated flow velocity occurs as a consequence of increased demand; deceleration as a consequence of reduced demand.

Assuming that water compression is insignificant and ignoring pipe elasticity, the magnitude of pressure surge (Dp) can be calculated from the formula below where the sign indicates the direction of pressure surge.

$$\Delta p = \frac{\Delta Q}{\Delta t} \times \frac{L}{A} \times \rho$$

where:

 $(\Delta Q/\Delta t) =$ flow velocity variation in (m³/s)s (acceleration/deceleration) L = pipe length in m

- $A = pipe cross section in m^2$
- ρ = water density in kg/m³

Both simulation and tests have shown that if the rate at which the flow controller changes the flow, taken together with the cross-section of the supply pipe and pipe length results in pressure surge greater than a certain size, there is a danger of self-oscillation. However, this can only happen if the control loop is elastic because a certain elastic cushion effect is necessary to start the process and maintain it.

If the elasticity of the control loop is very low, there is nothing to maintain the pressure oscillation and it will die away.

As can be seen from the formula, the size of pressure surge depends on the flow velocity change (DQ/Dt) which in turn is determined by how fast the pressure controller changes its kv value.

How large a pressure surge a given rate of opening and closing leads to is completely dependent on the length of the consumer branch and its crosssectional area. That is to say, the size of pressure surge is linearly proportional to the pipe length and inversely proportional to the crosssectional area. This means that increasing the inside diameter of the pipe by 41 % will halve the size of the pressure surge.

In addition, if the dimensions of the consumer supply pipe are so large that it can always transport the flow change created by the pressure controller sufficiently quickly, pressure oscillation cannot occur. In the case of individual systems, the diagram (fig. 2) can be used to indicate whether the installation lies in a critical area as far as pressure surge is concerned. If the consumer supply pipe is able to handle higher flow velocity variations than those the Rh value of the pressure controller makes possible, self-oscillation is almost excluded. However, what cannot be excluded is the occurrence of resonance oscillation. This is dealt with in the section "Self-oscillation".

Reaction oscillation

Reaction oscillation occurs, typically, in installations with relatively high system elasticity.

Even though reaction oscillation does occur in a system, it cannot be said to be unstable, but the condition does very strongly amplify a small pressure change in p1, see fig. 3. The reason is that because of the high system elasticity, pressure changes produce flow changes. Significant flow change creates a strong reaction in p2 which sometimes can cause the whole district heating pump control to oscillate. This, in turn, amplifies and maintains the oscillation problem.

The following conditions are characteristic of reaction oscillation:

 It occurs, typically, in direct radiator circuits (no mixing loop) which normally have high system elasticity.



FIGURE 2: Length of consumer branch pipe, flow and return

- It occurs, typically, on starting new block and district heating systems with associated supply network.
- It occurs and disappears spontaneously.
- It causes irregular oscillation times.
- It causes sudden pressure variations and uneven system pressure.
- The magnitude of pressure
 variations is very different from
 one oscillation to the next.
- Oscillating flow pressure and return pressure occur in the district heating network. Pressure surge is strongest in the stretch of pipe in which the pressure controller is installed. Oscillation can propagate to various pump controls and pressure maintenance valves. (Normally, pressure must be registered for a minimum of 30 minutes to establish the presence of this phenomenon).
- Knocking radiator valves because the pressure surges cause inverse pressure conditions in the radiator circuit (negative differential pressure during part of the oscillation period created by the pressure surges). The cause here is excess elasticity which means that the pressure controller is too slow in equalising the difference in pressure.

Reduction of reaction oscillations

Generally, damping the pressure controller is not especially effective against reaction oscillations because the severity of the damping required can cause knocking problems in radiator valves (because of negative differential pressure, a fig. 4, where the water flows backwards) if p1 momentarily falls below p2.

With new installations/connections, the whole system must be properly bled to ensure that compressibility is as little as possible, the main source of oscillation being excess compressibility in the control loop. (Starting problems because of the presence of air disappear relatively quickly when the connection has been made).

If because of a highly elastic system the above does not help, there are in principle only two ways of solving the problem:

Either the installation must be changed so that control loop elasticity becomes very low, or the pressure controller must be located in the least compressible part of the system. This is normally the stretch of pipe in which the control valve is located. (In direct connected radiator systems without mixing loop the radiator thermostats are considered to be control valves).

If this means that the pressure controller must be installed in the flow, a check must be made to ensure that the static pressure in the system is high enough to prevent air separation, i.e. at low pressure the water cannot contain as much air as at high pressure. In addition, hot water at the same pressure cannot contain as much air as cold water.

Self-oscillation

Self-oscillation occurs in individual systems because of the presence of three factors at the same time: system elasticity in the control loop, the control rate of the pressure controller, and the dimensions of the consumer supply pipe.



FIGURE 3

Self-oscillation creates unstable control within a wide operating range and in this condition random pressure change can create system oscillation. See fig. 5a.

Self-oscillation is conditional on the following:

- The pressure controller is able to change the flow velocity faster than the rate at which the velocity in the supply pipe can be changed.
- The system elasticity (in the part of the system containing the pressure control loop) must be large enough to create new pressure oscillation.
- Self-oscillation will be eliminated if just one of these preconditions is changed.
- The following conditions are characteristic of self-oscillation:
- Strong pressure oscillation in flow and return during operation, which disappears when flow through the system is shut off.

- Pulsating flow noise or rumbling, alternating with silence (...noise... silence...noise...silence).
- Oscillating frequencies between 0.2 Hz and 3 Hz.

Reduction of self-oscillation

Self-oscillation can be eliminated by changing one or more of the three factors that influence control.

Fig. 5b shows how self-oscillation in an indirect domestic installation can, in an emergency situation, be damped and eliminated using a 1 mm inside dia., 1.5 m long impulse tube (code no. 003H2330).

When the pressure controller is located in the flow pipe, a check should be made to ensure that the static pressure in the system is high enough to prevent air separation. See fig. 6. Self-oscillation can also be damped by changing the control rate of the pressure controller. This can be done as described in the section "The control rate of the pressure controller", i.e. by installing an impulse tube with high flow resistance.

The other very convenient solution is to instal a special high quality damping valve (code no. 003H0276 and 003G1401 for impulse tubes 6 mm and 10 mm accordingly).

However, this method cannot always be recommended. In particular it ought not to be used in installations having direct service hot-water exchange combined with a directconnected radiator circuit without mixing loop.

The reason is that this type of damping can give rise to knocking problems in radiator thermostats because of negative differential pressure created when hot water is used.



FIGURE 4

Resonance oscillation

This type of oscillation arises from selfoscillation and occurs where several pressure controllers, consumer supply pipe and the supply network are involved. Typically, resonance oscillation occurs in residential complexes where the concentration of pressure controllers is large and where pipes between individual systems are relatively short (e.g. grouped or terraced houses). Briefly, resonance oscillation is closely related to self-oscillation. But in this case, all the pressure controllers act as one large pressure controller because the pressure surge from the individual systems arrives simultaneously in the distribution network (the systems have the same time constant). This causes network problems as regards sufficiently rapid flow acceleration and deceleration. In cases where resonance oscillation occurs, most systems are individually

stable and in balance, but unfortunately too large a concentration of systems in relation to the dimensions/extent of the supply network means that when considered as an entirety, all systems can operate unstably. See fig. 7.

Resonance oscillation is often recognisable by the following conditions:

- Strong pressure oscillations in flow and return during operation. These do not disappear but at best can be reduced when flow through the individual system is shut off.
- Pulsating noise or flow noise alternating with silence (...noise... silence...noise...silence).
- Oscillation frequencies between 0.5 Hz and 0.1 Hz.



FIGURE 5







FIGURE 6

Reduction of resonance oscillation

Resonance oscillation can be reduced by damping the pressure controllers in part of the systems, but it is to be expected that its total elimination will necessitate damping over a large number of systems in the affected area. However, this method cannot always be recommended. In particular it ought not to be used in installations having direct service hot water exchange combined with directconnected radiator circuits without mixing loop.



Future applications

For the future, new applications should be designed to take account of the problems arising from the interrelationship between system elasticity in the control loop, the control rate of the pressure controller, and the dimensions of the consumer branch. The aim should be to make the elasticity in the control loop of the pressure controller as low as possible so that the danger of the types of oscillations just described can be avoided. When choosing application design, the problem around air separation must be remembered because this creates the traditional problems of poor cooling, no heat, noise, etc. In practice it has been observed that the whole district heating network becomes more stable when the experience described in this article is incorporated in the design of user installations. This applies especially to installations in new areas where only a few users are connected and where pipe dimensions are typically limited as much as possible, primarily for financial reasons, and also because the problems described have remained unknown until now.



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