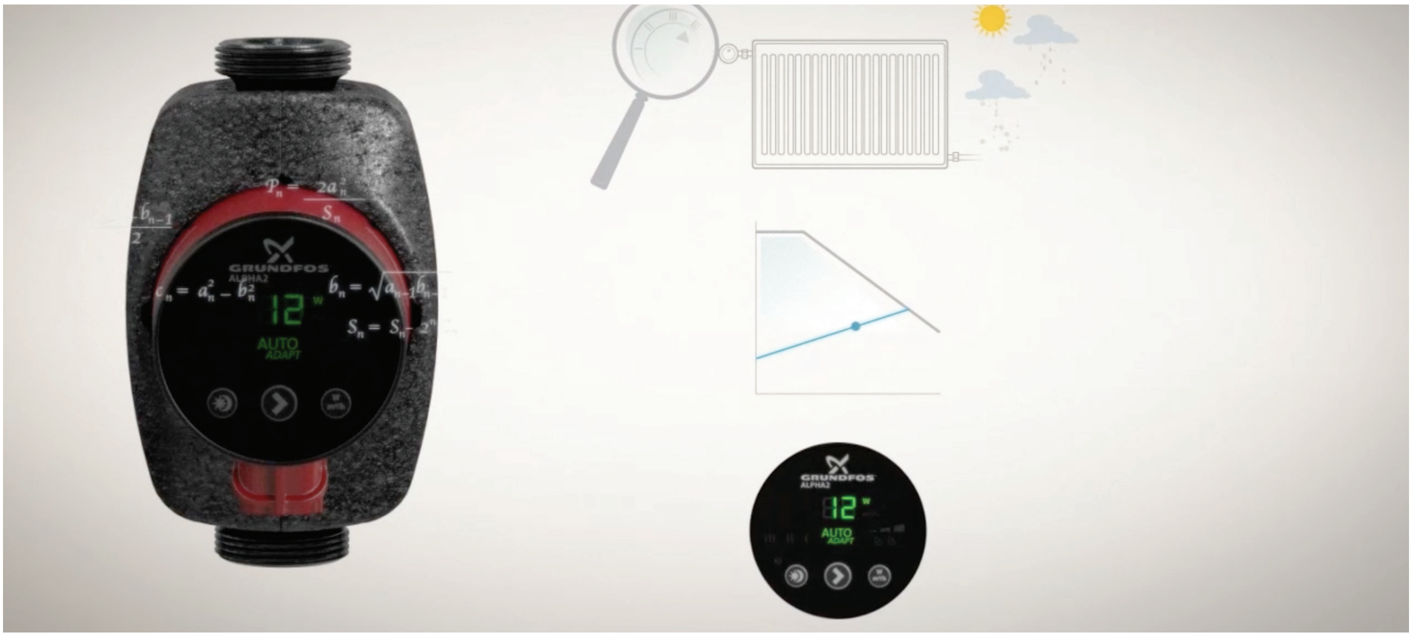

Adaptive selection of control-curves for domestic circulators

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Abstract

Speed controlled circulators for domestic heating system have been on the market since the early nineties. The majority of these circulators have built-in pump control curves, which adjust the speed and thereby the pressure to the actual flow and heat demand. Circulators normally have a variety of pump control curves to accommodate for variations in heating systems. This can further improve comfort and reduce energy consumption. To benefit from this option the right setting of the circulator pump control curve must be done after it is installed. In most cases this is not possible, because information about the particular heating system is not available. This paper describes a new control method - AUTO*ADAPT*, which automatically adapts the setting of the circulator to the heating system where it is installed. Circulators with AUTO*ADAPT* function measure and analyse the heating system characteristics during operation and adjust the setting of the pump control curve accordingly. Field test results from Germany have shown that in 75% of the cases the AUTO*ADAPT* had chosen a setting same comfort level and lower energy consumption.

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1. Introduction

Circulators are used in all water based heating system. These systems include radiator-heated systems and floor-heated systems. The heating source can be boilers, sun heating, heat pumps, and so forth. The task of the circulator is the same in all these systems despise their differences. That is to supply the pressure necessary for the heat control to control the water flows and thereby the heat flow to the house. A sketch of a simplified radiator heated system with a boiler is shown in *Fig. 1.*

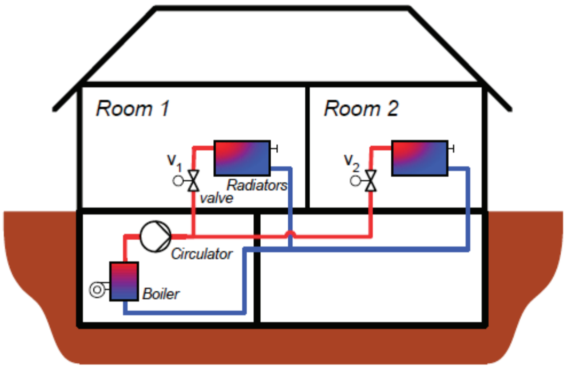

Fig. 1: A sketch of the piping structure of a central heating system in a two-room house. The central heating system is a two-pipe system, which is the most used system in real life applications.

The central heating system presented in this figure is a two-pipe system with heat control based on thermostatic valves. The task of the central heating system is to control the temperature in each room to a preset value chosen by the user. The mean for controlling the temperature is the thermostatic valve, and the heating source is the radiator, see *Fig. 1.* The heat energy delivered to the room is controlled by the temperature and flow of water through the radiator. The heat source (in *Fig. 1* a boiler) controls the temperature and the thermostatic valve controls the flow.

In the case shown in *Fig. 1* the boiler temperature set point is chosen such that the radiators can deliver the necessary amount of heat to the whole house. However, there are in general different needs in the two rooms in *Fig. 1.* The thermostatic valves handle these differences. That is by controlling the water flow the heat flow is controlled individually for each radiator, and thereby the temperature in each room of the house. This is exactly how the room temperatures are controlled in all central heating systems.

The thermostatic valves need a pressure to be able to control the water flow. The circulator delivers this pressure. To do that the circulator must overcome the back-pressure of the piping in the system and deliver sufficient excess pressure to enable the control by the thermostatic valves. Today high-end circulators have built in speed-control. This speed-control is used for reducing the pressure at part load. Thereby energy is saved and the performance of the thermostatic valves is improved. In circulators the pressure reduction at part load is implemented via a proportional-pressure-curve. For the 6 m ALPHA pump from Grundfos the initial proportional-pressure-curve is shown in *Fig. 2.*

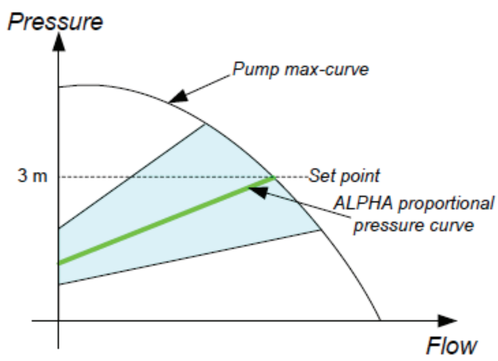

Fig. 2: Proportional-pressure-curve, used for control of circulators. The light blue area illustrates the area where the control curve can be placed dependent on the type and size of the central heating system.

The circulators with build in speed control have now been on the market for many years, and this is a proven technology. To utilize the full potential of the speed-controlled circulators it is important that the control curve is chosen correctly for a given heating system. The choice of the control curve should be based on the piping, radiators, and heat source in the system. Moreover, the level of insulation of the house is affecting the optimal position of the control curve. This shows that the control curve should be chosen based in knowledge, which traditionally is not available for the installer. Therefore, a large amount of circulators are not controlled on the optimal control curve for the given heating system.

To help the installer we propose an adaptation algorithm called AUTO*ADAPT*. This algorithm can adapt the control curve of the circulator to a curve, which is optimal for the given heating system. The AUTO*ADAPT*, proposed in this paper, is a further development version of the AUTO*ADAPT*, which has been available in the MAGNA circulators from Grundfos since 2001.

2. The new AUTO*ADAPT* algorithm

In the introduction it is argued that the choice of the control curve for the circulator affects the performance of the heating system and the use of electrical energy. Therefore it is important to choose the curve correctly. With AUTO*ADAPT* the choice of an optimal curve is automated. Hence the installer does only have to deal with the piping and the electrical connection when installing a circulator in the future.

In this section the functionality of the AUTO*ADAPT* is explained. However, for a deeper description we refer to (Kallesøe and Bidstrup (2008)). The functionality of the AUTO*ADAPT* can be divided into three tasks as illustrated in *Fig. 3*.

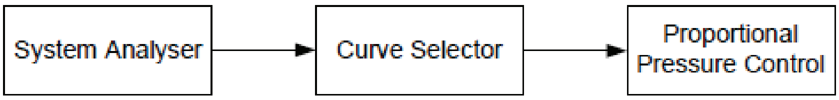

Fig. 3: The structure of the AUTOADAPT algorithm. The algorithm is composed into three tasks. These are an analysis task, a select task, and a control task.

The first task is to analyse the heating system in which the circulator is placed. The "System Analyser" does this. The analysis is aimed to tell if circulator pressure is too high, too low, or OK. The analysis part is explained in Section 2.1. The second task is to use the knowledge obtained from the System Analyser to select a proper proportional-pressure-curve for the circulator. The "Curve Selector" does this. The selector is described in Section 2.2. Finally, the circulator is control according to the selected proportional-pressure-curve. This is done according to the curve shown in *Fig. 2*. In the following the functionality of the first two blocks in *Fig. 3* is explained in details.

2.1 The System Analyser

The AUTO*ADAPT* algorithm adapts the proportional-pressure-curve to the conditions of the heating system in which the pump is placed. Supervising the load conditions of the heating system forms the basis for this adaptation.

To understand this first we must understand how the load conditions affect the flow and pressure of the circulator. Using a heating system, as shown in *Fig. 4*, the connection between the load conditions and the valve behaviour can be explained. For a more detailed explanation of how heating system works we refer to (Otto (1991), Petitjean (1994), Tiator (1998)).

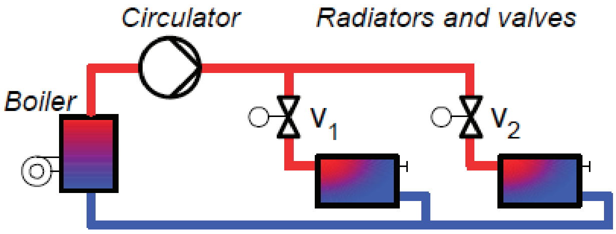

Fig. 4: Sketch of the piping of a simple two-pipe central heating system with thermostatic valves.

That is given a boiler set point the heat flow is controlled by the water flow through the radiators. The thermostatic valves control the water flow by controlling the pressure drop across valves. Therefore, if the circulator pressure is too high the pressure drop across the valves is high. This means that the valve is nearly closed most of the time, which results in poor temperature control. Moreover an oscillating behaviour is likely to occur in this case (Andersen *et* al., 2000), and acoustic noise might be created. This phenomenon is here denoted saturation downward. In the opposite case where the circulator pressure is too low the pressure drop across the valves is low. This means that the valves must be almost fully opened most of the time, which again implies poor temperature control.

To measure the average opening of the valves in the system we use the total hydraulic conductivity. This conductivity describes the total pressure loss in the system at a given flow. That is the pressure loss across the boiler, the piping, and the valves, see *Fig. 4*. As the pressure losses in the boiler and the piping is constant for a given flow, changes in the valve opening will results in changes in the hydraulic conductivity. The total hydraulic conductivity is found from the measurements available at the pump. Hence it is given by

$$k_{sys}\text{-}value = \frac{flow}{\sqrt{pressure}},$$

where the k_{sys}-value is the hydraulic conductivity, the flow is the flow through the pump, and the pressure is the pressure across the pump. The k_{sys}-value forms the basis for the analysis part of the AUTO*ADAPT* algorithm.

To explain the functionality of the System Analyser in the AUTO*ADAPT* algorithm we refer to *Fig. 5*, *Fig. 6*, and *Fig. 7*. In these figures the green curve shows changes in the k_{sys}-value over time. The red and blue curves are the maximum and minimum values of the k_{sys}-value. Here these are called k_{high} and k_{low} respectively. Finally the black curve divides the area between the red and blue curve into two sub-areas denoted area A and area B. The black curve is denoted k_{ref} and is calculated from the values of k_{high} and k_{low}. The level of saturation can be measured by comparing the amount of time where the k_{sys}-value is in area A compared to the time it is in area B. In *Fig. 5*, *Fig. 6*, and *Fig. 7* the curves are shown in three different situations.

In *Fig. 5* the circulator pressure is too low, meaning that the pressures across the valves are too low. As explained previously, when the pressure is too low the valves are not able to control the temperature properly. The low pressure conditions is seen in *Fig. 5*, as the time in which the k_{sys}-value (green curve) is in area B is larger that the time it is in area A. This is denoted saturation upwards.

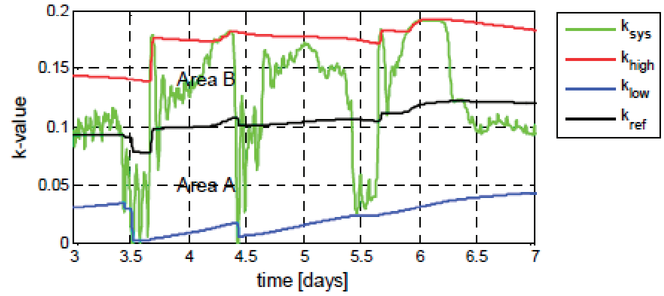

Fig. 5: Example of a time series of k_{sys}-values in a central heating system, where saturation occurs at when the valve is almost fully opened

In *Fig. 6* another time series of k_{sys}-values is shown. Here the circulator pressure is too high. This again results in poor temperature control. This high pressure conditions is seen in *Fig. 6* by the fact that the k_{sys}-value (green curve) is in area A in a larger amount of the time than in area B. This is denoted saturation downward.

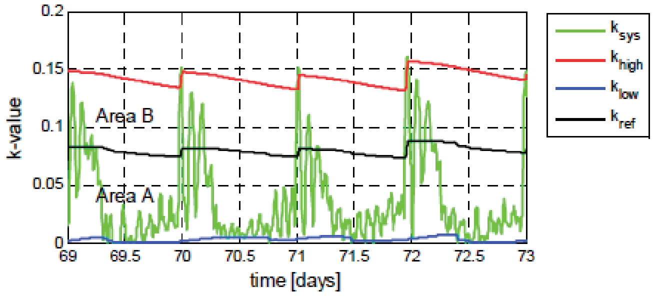

Fig. 6: Example of a time series of k_{sys}-values in a central heating system, where saturation occurs when the valve is almost closed.

In the case where the pressure has a reasonable value for the given heating system, the time where the k_{sys}-value is in area B is the same as the time it is in area A. This case is shown in *Fig. 7*.

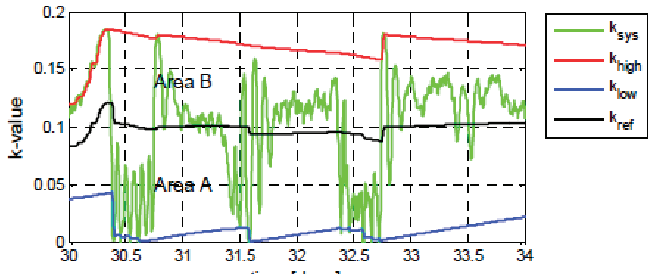

Fig. 7: Example of a time series of k_{sys}-values in a central heating system, where saturation do not occur.

From *Fig. 5* to *Fig. 7* it is seen that using evaluation of the time series of the k_{sys}-value it is possible to distinguish between systems with saturation upwards, saturation downwards, and no saturation. This is used in the AUTO-*ADAPT* algorithm to decide if the pressure should be increased, decreased, or leaved unchanged.

2.2 The Curve Selector

With the AUTO*ADAPT* algorithm the pressure is controlled using a traditional proportional-pressure-curve. This means that the task of the Curve Selector is to choose an optimal position of this proportional-pressure-curve given a heating system. That is the Curve Selector can choose any proportional-pressure-curve in the blue area of *Fig. 2*. The benefits of using the proportional-pressure-curve is that a well recognized method for pressure control is thereby inherited in the AUTO*ADAPT* control.

The optimal position of the proportional-pressure-curve is found using the analysis results obtained from the System Analyser presented in Section 2.1. That is when the pressure delivered by the pump is too low the heating system is not capable of delivering enough heat. Therefore, the valves in the system must be almost fully opened most of the time, and saturation upwards will occur. This is the case shown in *Fig. 5*. To overcome this the pressure should be increased, hence the proportional-pressure-curve should be increased. This is exactly what the AUTO*ADAPT* algorithm does.

In the opposite case where the pressure is to high the heating system is able to deliver too much heat, meaning that the valves are closed most of the time. This is the case shown in *Fig. 6*. To overcome this the pressure should be decreased, hence the proportional-pressure-curve should be decreased. This again is exactly what the AUTO*ADAPT* algorithm does.

In the case where the k_{sys}-curve is equally distributed between area A and B the system is not saturated, see *Fig. 7*. This means that there are no reasons for changing the pressure. Hence the AUTO*ADAPT* algorithm does not change the position of the proportional-pressure-curve.

3. CONCLUSIONS

In this paper an adaptation algorithm for small circulators, call AUTO*ADAPT*, is presented. This algorithm is able to adapt the pressure curve of the circulator to fit the heating system in which the circulator is installed. This easy the installation of speed-controlled circulators, as the installer does not have to used time on finding the optimal pressure curve any more.

The algorithm has been tested in a field test containing 120 field-test hosts from Germany. The results of this field-test shows that the field-test hosts have been either satisfied or very satisfied with the performance of the algorithm. Moreover the field-test shows that in 75.2% of the heating system the AUTO*ADAPT* has reduced the pressure compared to the initial position of a standard ALPHA2 circulator. Therefore, electrical energy is saved at 75.2% of the hosts without affecting the comfort. In only 11.4% of the field-test hosts the AUTO*ADAPT* has increased the pressure compared to the standard setting of the ALPHA2 circulator. In these cases it is expected that the user would have to manually change the setting, if a circulator without AUTO*ADAPT* where installed. This indicates that it is possible to save electrical energy using the AUTO*ADAPT* without affecting the comfort in most applications.

In this paper the functionality of the AUTO*ADAPT* is explained via a 2-pipe heating system with thermostatic valves. However, the algorithm works equally well on for example a floor-heated system. This is also shown by the fact that a variety of different heating systems where included in the field test. Hence the AUTO*ADAPT* works in different types of heating systems.

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