

# Efficiency Evaluation of Proportional Pressure Control for Centrifugal Pumps with Variable-Speed Motors

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## ABSTRACT

*The goal of this research is the derivation of the theoretical approximation tool for evaluation of efficiency improvement potential applying the proportional pressure control for variable speed pumps in heating systems. The proportional pressure control was compared with the constant differential pressure control. For this reason, energy calculation analyses were realized for centrifugal pumps. The interaction was found between the energy consumption, heating water leakage, and declination of pump proportional pressure control curve at the specific load profile.*

*The results show that the reduction of annual energy consumption can be achieved up to 48% and the reduction of annual heating water leakage, up to 24% of the existing pipe leakage rate, if the proportional pressure control is applied and the declination of pump proportional pressure control curve is up to 90%.*

## INTRODUCTION

Today with the rapid increase of energy production costs in the world, higher attention is paid on improvement of energy efficiency level. About 20% of the total electrical energy produced in the world is consumed by pumps and pumping systems and almost half of that can be saved up (Giribone et al. 2006).

A lot of scientific papers are dedicated to the energy efficiency investigation in centrifugal pump technology (Bidstrup et al. 2002; Hegberg 1991; Kaya et al. 2008; German Blue Angel Labelling Scheme 2002). Some of the research works show the results of the experimental measurements of variable speed pumps. Some of the research works show the theoretical approach on energy calculation for variable speed pumps in heating systems etc.

The evaluation of efficiency improvement potential applying the proportional pressure control for variable speed pumps in heating systems is very important, while normally pumps are operating via constant differential pressure control. The energy improvement evaluation tool can be derived taking into account a specific load profile of variable flow heating systems and then realizing various energy calculations.

With the certain research focused on the evaluation of operation of pumping systems, it's possible to substantially increase the total level of efficiency in engineering networks, thus contributing to energy saving in the world.

## APPROXIMATION TOOL FOR EVALUATION OF EFFICIENCY IMPROVEMENT POTENTIAL APPLYING THE PROPORTIONAL PRESSURE CONTROL VERSUS THE CONSTANT DIFFERENTIAL PRESSURE CONTROL MODE

It's very important to select an appropriate pump control mode for the respective engineering system (Palgrave 2003; Machine Design 2002). The selection should always be done with a focus on the highest possible level of energy efficiency and reliability. Among a variety of variable speed pump control modes (Figure 1), proportional pressure control mode was analyzed in the research (Machine Design 2002).

The proportional pressure control mode was compared to the constant differential pressure control mode.

Main circulators (Figure 2) are normally controlled via constant differential pressure or proportional pressure control mode (World Pumps 2009). The proportional pres-

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sure control mode is the most efficient mode of the control for main circulators. Thus it's crucial to estimate the potential reduction of energy consumption if the proportional pressure control is used in comparison with the constant differential pressure control.

Proportional pressure control mode is generally recommended in systems where the common losses are relatively large, and the pressure drop, split between common losses and control valves, is mostly dedicated to the common losses (World Pumps 2009). Thus the proportional pressure control is advisable to use in heating and district heating systems with relatively long piping network.

It has been assumed that max 90% of the pressure drop comes to the common losses, and 10% of the pressure drop comes to the control valves.

The following equations (1–3) show the relationships among rotational speed, flow rate, head and power values when variable speed drive is used for centrifugal pumps (Giribone et al. 2006; Palgrave 2003).

$$\frac{Q_n}{Q_x} = \frac{n_n}{n_x} \tag{1}$$

$$\frac{H_n}{H_x} = \left(\frac{n_n}{n_x}\right)^2 \tag{2}$$

$$\frac{P_n}{P_x} = \left(\frac{n_n}{n_x}\right)^3 \tag{3}$$

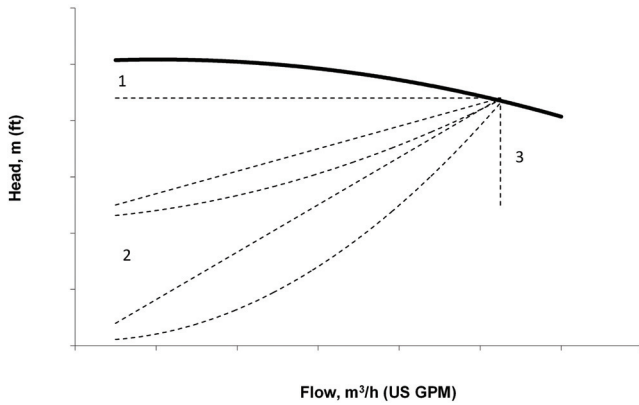
Besides that, the proportional pressure control mode should be used if two-way control valves are installed in the system (Palgrave 2003). The pump will reduce the speed if the valve is closing. The adjusted head value is being adapted in accordance with flow variations during the heating process, if the proportional pressure control is used (Machine Design 2002).

The load profile of a pumping system for a certain part of a district heating system should be taken into account in order to analyze the consumption of electrical energy if the certain declination of pump proportional pressure control curve is used (Figure 3).

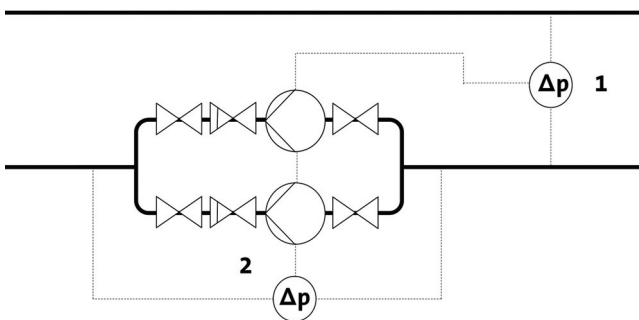
The annual operation of the pumping system is assumed as 6840 hours and the load profile is divided into four parts with different flow values: 100%, 75%, 50%, and 25% of flow rate in duty point (Pump School 1998; German Blue Angel Labelling Scheme 2002; Europump 2001). In its turn, each flow component corresponds to certain duration of operational time (according to the Blue Angel profile) (German Blue Angel Labelling Scheme 2002).

Each flow component corresponds to a certain duration of operational time in the following way (Figure 4):

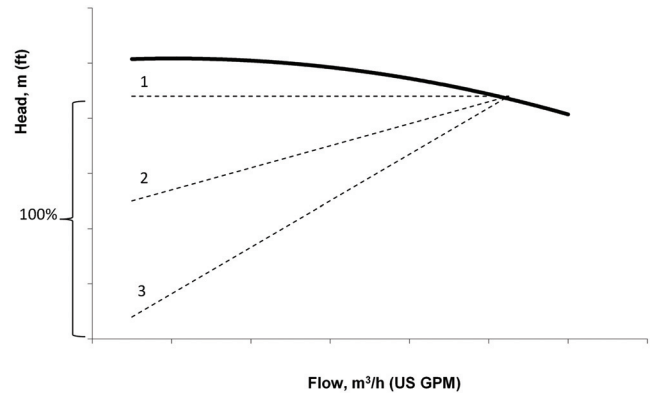
- 100% ≥ 6%,
- 75% ≥ 15%,
- 50% ≥ 35%,
- 25% ≥ 44%.



**Figure 1** Pumps' control modes [1: constant differential pressure control mode; 2: proportional pressure control modes (with linear/square influence); 3: constant flow control mode].



**Figure 2** Main circulators in district heating system (1: measured proportional pressure control, 2: constant differential pressure control or calculated proportional pressure control).



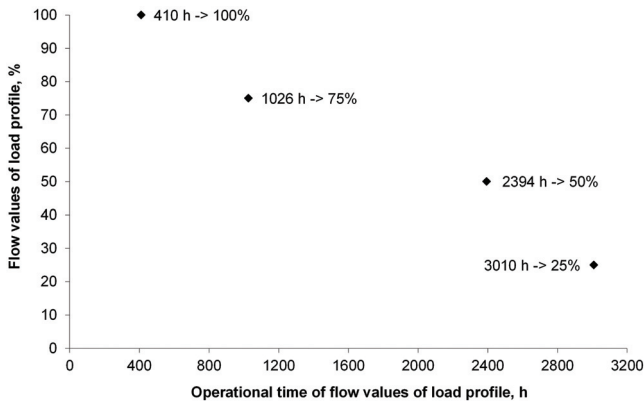
**Figure 3** Control modes of main circulators (1: constant differential pressure control mode; 2 and 3: calculated proportional pressure control mode with linear influence).

The energy consumption of proportional pressure variants was compared to the energy consumption of constant differential pressure control.

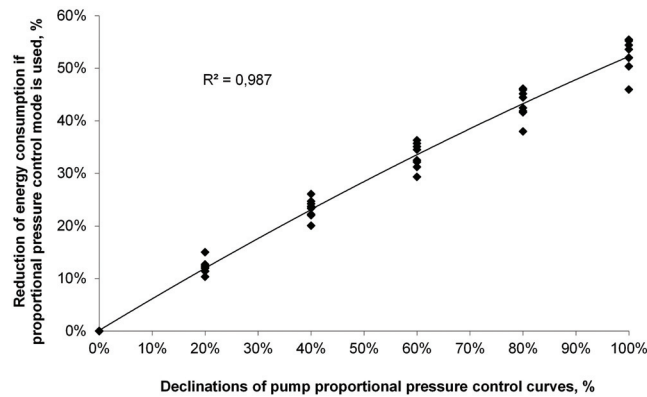
The calculation of annual energy consumption for centrifugal pumps of various designs was carried out during the analysis of the calculated proportional pressure control mode with the certain declinations of pump control curves (20%, 40%, 60%, 80%, and 100%) (WinCAPS 2011; Wilo-Select 2010) (Figure 5).

The regression equation of polynomial trend type ( $y = a_0 + a_1 \cdot x + a_2 \cdot x^2 + \varepsilon$ ) and the respective coefficient of determination ( $R^2$ ) was derived (Figure 5).

$$y_1 = -0.0891 \cdot x^2 + 0.6102 \cdot x + 0.0014 \quad (4)$$



**Figure 4** Assumed load profile of main circulators in district heating system (German Blue Angel Labelling Scheme 2002).



**Figure 5** Reduction of energy consumption, if certain declinations of pump proportional pressure control curves with linear influence are applied (in comparison with the constant differential pressure control).

Equation 4 can be used as a tool for evaluation of the potential reduction of energy consumption at different declinations of pump proportional pressure control curves. The potential reduction of energy consumption is estimated in comparison with the constant differential pressure control mode, if the value of duty point remains invariable.

Various limitations which were taken into consideration during the energy cost calculation are as follows:

- Calculated proportional pressure control mode with linear influence was chosen.
- Each duty point is met with its appropriate pump.
- The deviation from pump efficiency optimum is up to 3% for each duty point.
- The declinations of pump proportional pressure control curves vary from 0% up to 100%.

During the study, eight centrifugal pumps of various designs were analyzed (WinCAPS 2011; Wilo-Select 2010).

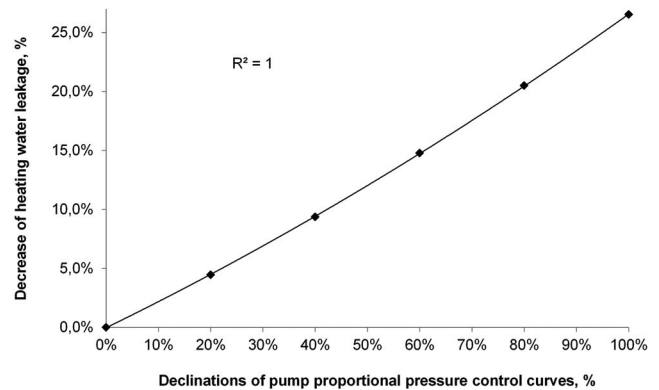
### Evaluation of the Reduction of Heating Water Leakage

Heating water leakage can be significantly decreased, if the proportional pressure control is applied for variable speed pumps.

$$C = \sqrt{2 \cdot g \cdot H} \cdot 0.6 \quad (5)$$

The Torricelli's equation (Wayne State University 2010) can be used to determine the decreased level of heating water leakage in a piping system by decreasing the head value of the pump (Equation 5).

The regression equation of polynomial trend type ( $y = a_0 + a_1 \cdot x + a_2 \cdot x^2 + \varepsilon$ ) and the respective coefficient of determination ( $R^2$ ) was derived (Figure 6).



**Figure 6** Annual decrease of heating water leakage (as a part of the existing leakage rate) at the different declinations of pump proportional pressure control curves, if the proportional pressure control with linear influence is applied (in comparison with the constant differential pressure control).

$$y_2 = 0.0494 \cdot x^2 + 0.2165 \cdot x - 0.0003 \quad (6)$$

Equation 6 can be used as a tool for evaluation of the potential reduction of heating water leakage of the existing leakage rate in the piping system at different declinations of pump proportional pressure control curves. The potential reduction of the leakage is estimated in comparison with the constant differential pressure control mode, if the value of duty point remains invariable.

## CONCLUSION

The results of this research show that the reduction of annual energy consumption can be achieved up to 48% for main circulators and the reduction of annual heating water leakage up to 24% of the existing pipe leakage rate. This reduction of energy consumption can be achieved, if the pump proportional pressure control is applied in comparison with the constant differential pressure control mode and the declination of pump proportional pressure control curves is up to 90% from the duty point head value. The pressure drop over the control valves is assumed as 10% of the total pressure drop in the system.

The higher the level of the declination of pump proportional pressure control curves is, the higher level of energy saving is.

## NOMENCLATURE

$y_1$	= reduction of energy consumption, if certain declination of pump proportional pressure control curves is applied (in comparison with constant differential pressure control) in %
$x$	= declination of pump proportional pressure control curves in %
$Q$	= centrifugal pump flow rate in m <sup>3</sup> /s (gpm)
$H$	= centrifugal pump head in m (ft)
$P$	= power in kW (HP)
$n$	= pump rotation speed in RPM
$C$	= water speed at pipe rupture in m/s (ft/s)
$y_2$	= annual decrease of heating water leakage, if certain declination of pump proportional pressure control curves is applied (in comparison with constant differential pressure control) in %

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