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Method of evaluation of efficiency improvement potential for water supply systems with focus on variable speed centrifugal pumps

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Abstract

The goal of this research is the derivation of the method for evaluation of efficiency improvement potential for public water supply systems with a focus on centrifugal network pumps. The efficiency of proportional pressure control usage has been analyzed for variable speed pumps. It has been done if proportional pressure control is used in comparison with constant pressure control mode. For this reason, energy calculation analyses have been realized for variable speed centrifugal pumps, and the theoretical tool of estimation of the efficiency improvement potential for public water supply systems has been derived. The conclusions are as follows: (1) it has been found that 1110 MWh of annually consumed electrical energy can be saved up, if the control mode of variable speed network pumps will be changed from constant pressure to proportional pressure control mode with the deviation of 20 % from head value of duty point at zero flow; (2) about 13 MWh of annually consumed electrical energy can be saved up, if the proportional pressure control mode with the deviation of 15 % will be changed to the deviation of 20 %; (3) totally about 1123 MWh or 1.12 GWh (14 % of the annually consumed electrical energy by variable speed network pumps) can be saved up in small public water supply systems in Latvia.

1 Introduction

About 10 % of the total electrical energy produced in the world has been consumed by pumps and pumping systems and more than half of that can be saved up (Giribone et al., 2006).

It is very important to determine the space for improvement for public water supply systems with a focus on variable speed centrifugal pumps.

Approximately 332 700 m^3 (LBN 222-99, 2000) of drinking water is daily produced at all public water supply systems in Latvia. About 141 000 m^3 (LBN 222-99, 2000) of drinking water is daily produced at small cities (up to 10 000 inh.). It has been assumed

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that about 8 GWh of annually consumed electrical energy comes to network pumping systems for distribution of drinking water in public water supply systems in small cities.

Variable speed centrifugal pumps in public water supply system are normally controlled via constant pressure (Palgrave, 2003; Lobanoff et al., 1992). The proportional pressure control mode is the most efficient mode of the control for booster pumps in public water supply systems.

The closer proportional pressure control curve is to the system curve, the higher level of efficiency can be obtained. In order to make an evaluation of the efficiency improvement potential for public water supply systems the proportional pressure control has been compared with the constant pressure control mode.

The proportional pressure control is generally recommended to be used in the systems where the total pressure drop is mostly dedicated to the piping system (1). Thus the proportional pressure control is advisable to use in water supply systems with relatively long piping network.

The usage of the proportional pressure control mode for variable speed centrifugal pumps in public water supply systems in small cities (up to 10 000 inh.) in Latvia is shown in Fig. 1.

It is important to evaluate the energy improvement potential of 95 % of booster pumps in small public water supply systems. And it is possible to estimate the saving potential if the deviation from head value of duty point at zero flow will vary from 15 % up to 20 %. It has been assumed that 80 % of the total head value is related to static head in the systems.

With focus on the evaluation of pumps' operation, it is possible to increase the efficiency of public water supply networks, thus contributing to energy saving.

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2 Development of the method of evaluation of efficiency improvement potential for public water supply systems with focus on variable speed centrifugal pump

During the development of the method for evaluation of efficiency improvement potential for public water supply systems the proportional pressure control mode has been compared to the usage of constant pressure control mode.

In order to analyze the consumption of electrical energy, if proportional pressure control mode with the deviations from head value of duty point at zero flow is used, as it is seen from Fig. 2, the load profile of pumping system of public water supply system should be taken into account.

It has been assumed that annual operation of pumping system in public water supply systems is 3285 h (ButK Consortium, 2007) and the load profile is divided into five parts with the flow values: 100 %, 75 %, 55 %, 35 % and 12 % of flow rate in duty point as it is shown in Table 1. Each flow rate corresponds to certain duration of operational time as a part of the total duration of operation per year.

Each flow component corresponds to certain duration of operational time (Fig. 3):

- 100 % → 5 %;
- 75 % → 9 %;
- 55 % → 14 %;
- 35 % → 27 %;
- 12 % → 45 %.

The energy consumption has been analyzed if proportional pressure control mode comes as alternative to constant pressure control mode for the same system.

Equations (1–6) show the relationships among rotational speed, flow rate, head, power and efficiency values (Vilner et al., 1976; Frenkel, 1956; Roberson et al., 1997;

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Bernier et al., 1999) when variable speed drive is used for centrifugal pumps.

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

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

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

$$\frac{\eta_n}{\eta_x} = 1 \tag{4}$$

$$\eta_{\mathrm{TOT}} = \eta_{\mathrm{P}} \cdot \eta_{\mathrm{M}} \cdot \eta_{\mathrm{FC}} \tag{5}$$

$$\eta = \frac{P_H}{P_1} = \frac{\rho \cdot g \cdot Q \cdot H}{P_1} \tag{6}$$

The Table 1 shows the change of head values at the flow divisions at the deviations within the range of 0–80 % from head value of duty point at zero flow (Grundfos Management, 2010).

During the analysis of the proportional pressure control mode with the deviations of 20 %, 40 %, 60 % and 80 % from head value of duty point at zero flow there has been carried out the calculation of annual energy consumption for centrifugal pumps (Fig. 4).

It is found, that the regression Eq. (7) of the linear trend type ($y = a_0 + a_1 \cdot x + \varepsilon$) can evaluate the efficiency improvement potential for public water supply systems with variable speed centrifugal pump, if proportional pressure control is used.

$$y = (0.63 \pm 0.02) \cdot x + 0.02 \pm 0.01 \tag{7}$$

The Eq. (7) can be used as a tool for evaluation of the potential reduction of energy consumption, if proportional pressure control is used with the deviations within the range of 0–80 %. The potential reduction of the energy consumption is estimated in

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comparison with the usage of constant pressure control mode, if the value of duty point remains invariable.

There are various limitations which have been taken into consideration during the energy consumption. The limitations are as follows:

- Calculated proportional pressure control mode with linear influence has been chosen;
- Each duty point is met with appropriate pump;
- The deviation from pump efficiency optimum is up to 3 % for each duty point;
- The deviation from head value of duty point at zero flow varies from 0 to 80 %.

During the study the energy analyses of 8 variable speed centrifugal pumps have been realized.

3 Verification of the method of evaluation of efficiency improvement potential for public water supply systems with focus on variable speed centrifugal pump

The measurements were done in the public water supply system (second stage boosting station) which supplies water to 2000 inhabitants in the town. The water supply systems is described with the following parameters:

- Drinking water consumption is about 131 400 $m^3\,yr^{-1}$,
- Daily drinking water consumption is about 360 $m^3\,day^{-1}$,
- Max drinking water consumption per hour is 36 $m^3\,h^{-1}$,
- Head value after boosting station is 3.5 bar $\approx$ 35 m,
- Water leakage in network is $\sim$ 20 %.

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Pressure boosting station is described with following parameters:

- Boosting station consist of 5 pumps (1 – drinking water pump, 2 – firefighting pumps, 2 – stand by pumps),
- All pumps are with built-in frequency converters for variable flow,
- Each pump is with nominal flow/head: $45\,m^3\,h^{-1}$ @ 60 m,
- Each pump has a motor of $P_2 = 11$ kW,
- Each pump has a maximum efficiency (BEP) of 64.8 %,
- Pumps are controlled via constant pressure control mode: 35 m after boosting station,

The following working parameters have been measured during the analysis of comparison of constant and proportional pressure control modes:

- Flow value per hour ($m^3\,h^{-1}$),
- Pressure value (bar),
- Power value (W),
- Electrical energy consumption (kWh).

Each of these parameters used to be measured every 30 min during one month (29 days).

The measurements were done in two steps using monitoring program – each pump control mode has been realized during a month.

Proportional pressure pump control mode was realized at the certain deviation of the head value from the duty point at zero flow: 15 %. This value of the deviation was chosen in order to provide a constant pressure level at the distal end-user across the day-night period. A constant pressure level at the critical end-user is provided at both minimal and maximal flow rates.

Hydraulic friction losses across the whole network are 5 m or 15 % from the total head value of the duty point.

Electrical energy consumption (kWh) is shown in Fig. 5, if the deviation is 35.7 % and 64.3 %. The rest 30 m is related to the static head which consist of maximum building height (12 m), topography height (3 m) and pressure value at a tap (15 m).

The measurements of the head, power and energy values are shown in Figs. 5, 6 and 7.

Having realized proportional pressure control mode (if the deviation of head value from the duty point is 15 %) – the pump head value is being decreased with the flow decrease.

Using proportional pressure control mode the flow value is varying from 6 $m^3 h^{-1}$ up to 33 $m^3 h^{-1}$, as it is seen in Fig. 8. The measured pressure values after boosting station vary from 2.9 up to 3.5 bar within this flow range.

The pumping station activates "night mode" if the flow value is being decreased less than 6 $m^3 h^{-1}$. Then the pumps are being stopped (pressure values vary from 2.8 up to 3.4 bar at zero flow).

The real measured saving potential of electrical energy is 10.9 %, if constant pressure and proportional pressure control modes are compared (proportional pressure with the deviation of 15 %).

By applying the evaluation tool (evaluation method of savings' potential if proportional pressure control mode is applied for boosting pumps in comparison with constant pressure control mode) the calculated saving potential of electrical energy is 11.5 %.

$$y = 0.63 \cdot x + 0.02 = 0.63 \cdot 0.15 + 0.02 \approx 11.5\,\%.$$

Accuracy within 9.3 % is performed if the theoretical evaluation tool has been compared with on the field measured data at district heating system.

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4 Conclusions

8 GWh of annually consumed electrical energy comes to variable speed centrifugal pumps for distribution of drinking water in public water supply systems in small cities (up to 10 000 inh.). About 95 % of network pumps are operating via constant pressure control mode. About 5 % of network pumps are operating via proportional pressure control mode and the average deviation from head value of duty point at zero flow is 15 % (can be achieved 20 %).

1. In this research it has been found that 1110 MWh of annually consumed electrical energy can be saved up, if the control mode of variable speed network pumps will be changed from constant pressure to proportional pressure control mode with the deviation of 20 % from head value of duty point at zero flow.

2. 13 MWh of annually consumed electrical energy can be saved up, if the proportional pressure control mode with the deviation of 15 % will be changed to the deviation of 20 %.

3. Totally about 1123 MWh or 1.12 GWh (14 % of the annually consumed electrical energy by variable speed network pumps) can be saved up in small public water supply systems in Latvia.

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Nomenclature

g	Acceleration of gravity ($9.81\,\mathrm{m\,s^{-2}}$)
H	Pump head (m)
P_1	Pump motor input power (kW)
P_H	Power delivered to pumped liquid (kW)
Q	Flow rate ($\mathrm{m^3\,s^{-1}}$)
R^2	Coefficient of determination
x	Deviation from head value of specific duty point at zero flow (%)
y	Reduction of energy consumption if the calculated proportional pressure control with deviations from head value of duty point at zero flow is applied, in comparison with constant differential pressure control mode (%)
η_P	Efficiency of pump (%)
η_M	Efficiency of motor (%)
η_FC	Efficiency of frequency converter (%)
η	Efficiency of complete pump unit: pump and motor (%)
η_TOT	Total efficiency of complete pump unit with frequency converter (%)
ρ	The density of the pumped liquid ($\mathrm{kg\,m^{-3}}$)

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Table 1. Deviations from head value of duty point if proportional pressure control mode is used with linear influence.

Deviations from head value of duty point at zero flow (%) \ Flow division (%)	100	75	55	35	12
0	100	100	100	100	100
20	100	95	91	87	82
40	100	90	82	74	65
60	100	85	73	61	47
80	100	80	64	48	30

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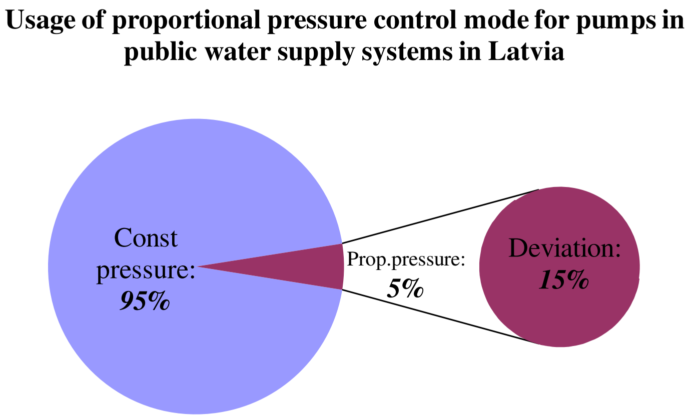

Fig. 1. Usage of proportional pressure control mode vs. constant pressure control mode for centrifugal pumps in public water supply systems in Latvia.

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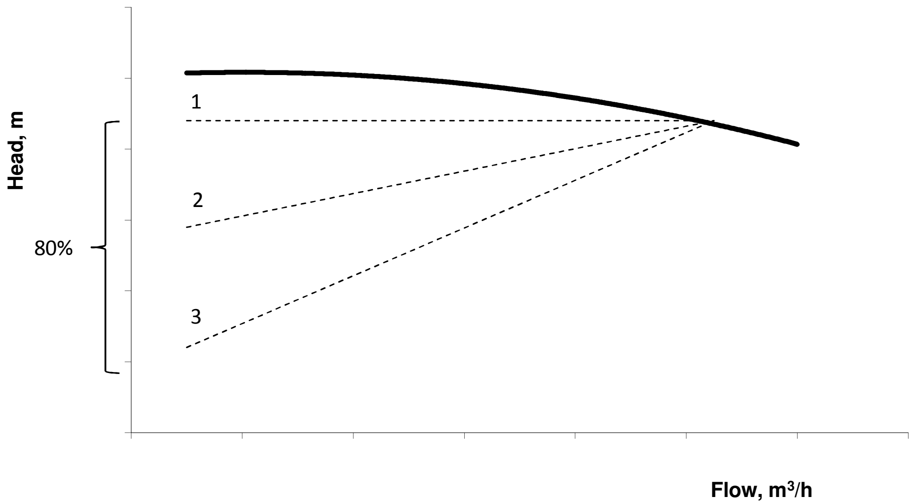

Fig. 2. Control modes for booster pumps in public water supply systems (proportional pressure control modes with linear influence).

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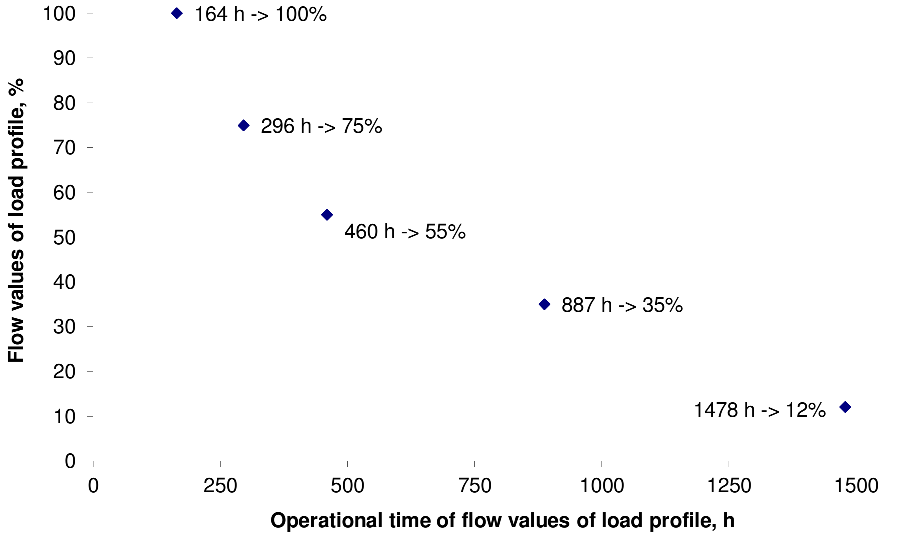

Fig. 3. Load profile of booster pumps in public water supply system (ButK Consortium, 2007).

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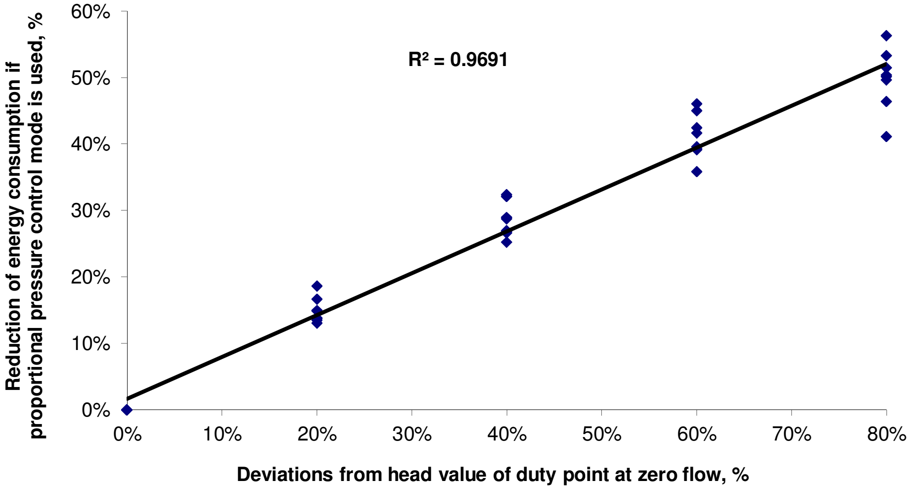

Fig. 4. Reduction of energy consumption, if calculated proportional pressure control is used with the deviations within the range of 0–80 % from head value of duty point at zero flow (in comparison with constant pressure control mode).

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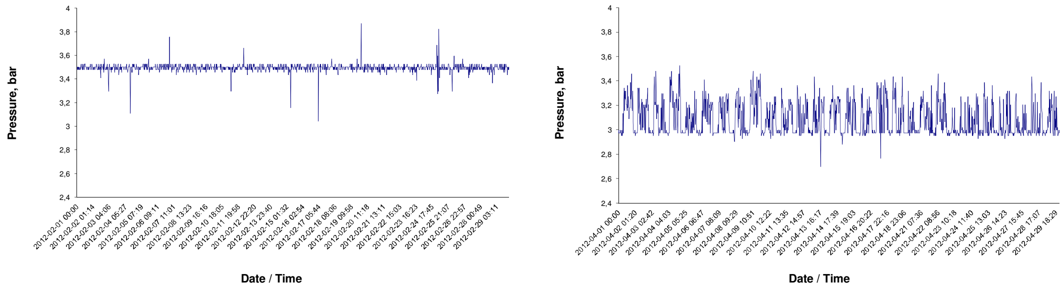

Fig. 5. Pressure values (from left: constant pressure control mode; from right: proportional pressure control mode).

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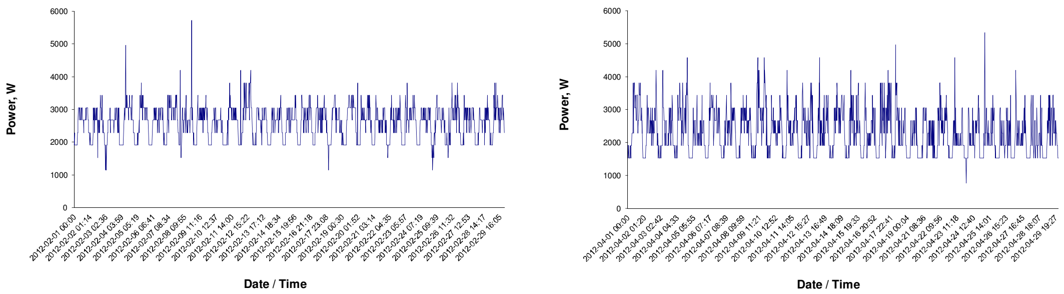

Fig. 6. Power values (from left: constant pressure control mode; from right: proportional pressure control mode).

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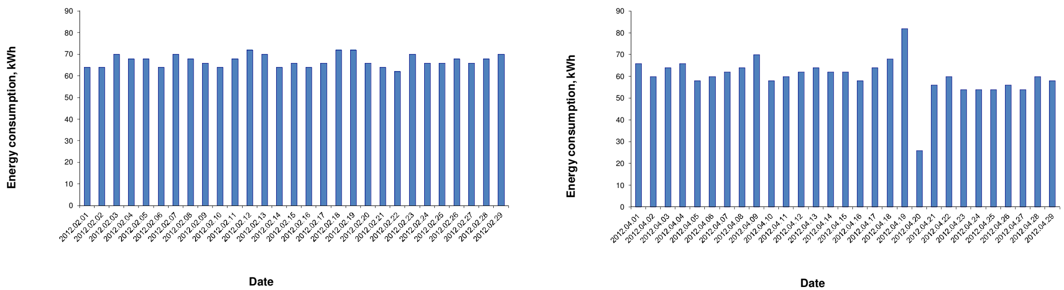

Fig. 7. Energy consumption values (from left: constant pressure control mode; from right: proportional pressure control mode).

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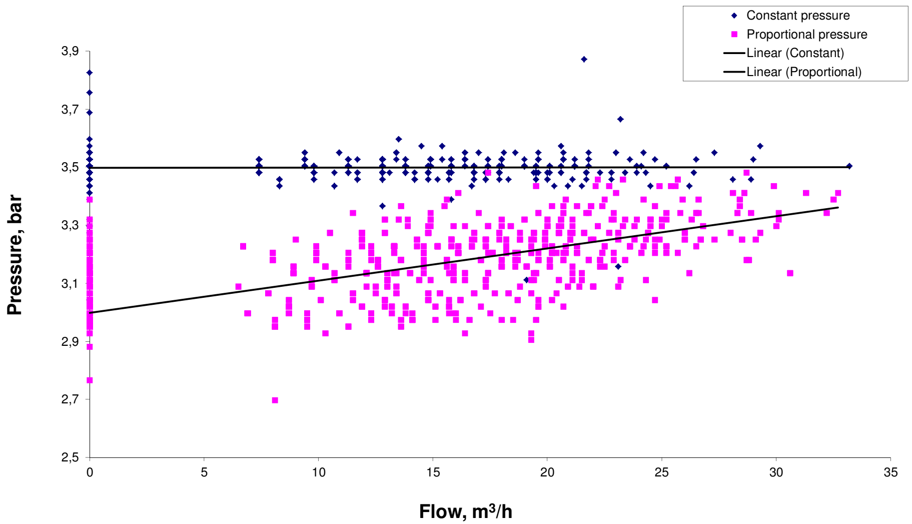

Fig. 8. Pressure and flow values if constant and proportional pressure control modes are realized.

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