CRITERIA OF EFFECTIVENESS EVALUATION OF VARIABLE SPEED CENTRIFUGAL PUMPS IN HEATING AND COOLING SYSTEMS

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Abstract
The goal of this study is the derivation of evaluation criteria for effectiveness of variable speed circulators used in heating and cooling systems.
Proportional pressure control mode has been analyzed as a criterion for centrifugal pumps. For this reason, a great number of energy analyses have been realized for different pumps and a regression equation with a corresponding coefficient of determination has been derived.
As the result, the trend of reduction of energy consumption has been determined if the proportional pressure control mode is used in comparison with constant differential pressure control mode. The control modes are compared if the value of the duty point remains invariable for both modes. It has been found that the reduction of annual energy consumption can be achieved up to 33% if the proportional pressure control mode is applied with the deviation of 60% from the head value of duty point at zero flow.
There is also the change of efficiency level of circulators has been investigated in the article. It has been done at different deviations from nominal pump head. The regression equation with coefficient of determination has been derived.
Finally, it has been derived that the efficiency level drops up to 3% if variable speed centrifugal pumps are applied, and the deviation of the head value of best efficiency point (BEP) is up to 30% from its nominal value. A slight decrease of efficiency level is observed if the deviation from the nominal head value is up to 30%. If the head deviation is above 30% from its nominal value, then the efficiency level drops rapidly.
Key words: centrifugal pump, control mode, efficiency.

Introduction

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

There are a lot of technical aspects which should be taken into consideration in order to optimize operation of pumping systems with a focus on pump control modes. Each separate pumping system is described with its own specific features and is thus characterized with an individual approach.

Selecting the pumping technology is also very crucial if the duty point is located at the most optimal zone of pump curve, thus achieving the highest possible level of energy efficiency.

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.

Materials and Methods

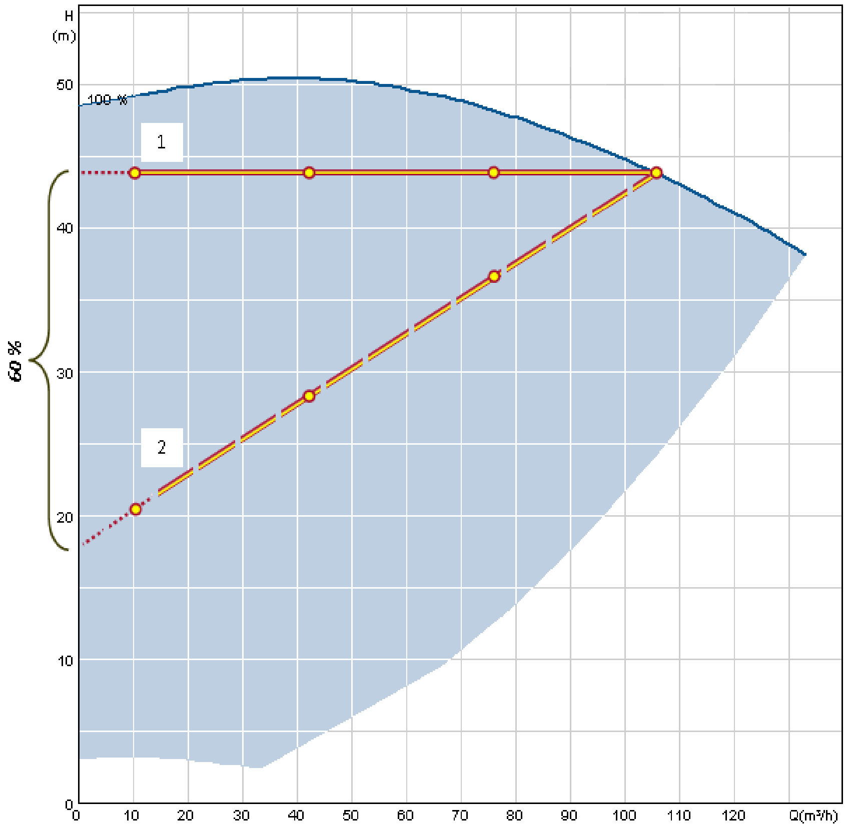
Evaluation of savings’ potential if the proportional pressure control mode is applied for circulators in comparison with constant differential pressure control mode

Circulators are normally controlled via the constant differential pressure or proportional pressure control mode in heating and cooling systems (Machine Design by Engineers for Engineers, 2002). The proportional pressure control mode is the most efficient mode of the control for circulators. Thus it’s very crucial to estimate the potential reduction of energy consumption if proportional pressure control is used in comparison with constant differential pressure control.

The proportional pressure control mode is generally recommended for the systems where the pressure drops, splits between piping system and control valves, is mostly dedicated to the piping system (Skovgaard, A., 2004). Thus the proportional pressure control is advisable to use in heating and cooling systems with relatively long piping network.

Besides that, the proportional pressure control mode should be used if two-way control valves are installed in the system (Skovgaard, A., 2004). 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 mode is used.

The load profile of heating system is taken into account in order to analyze the consumption of electrical energy of pumping system if the proportional pressure control mode with different deviations from the head value of duty point at zero flow is used.



Source: Grundfos Management A/S, 2011

Figure 1. **Control modes for circulators (1 – constant differential pressure control mode; 2 – calculated proportional pressure control mode with linear influence)**

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

Each flow component corresponds to certain duration of operational time in the following way (Trinath S., Amitabh G., 2009):

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

The energy consumption, having realized a variety of proportional pressure variants, has been compared with the energy consumption if the constant pressure control mode is applied.

During the analysis of the calculated proportional pressure control mode with different deviations from the head value of duty point at zero flow rate (20%, 40% and 60%), there has been carried out the calculation of annual energy consumption for centrifugal pumps of various designs (Pump School, 1998; KSB Aktiengesellschaft, 2010) (Figure 1).

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

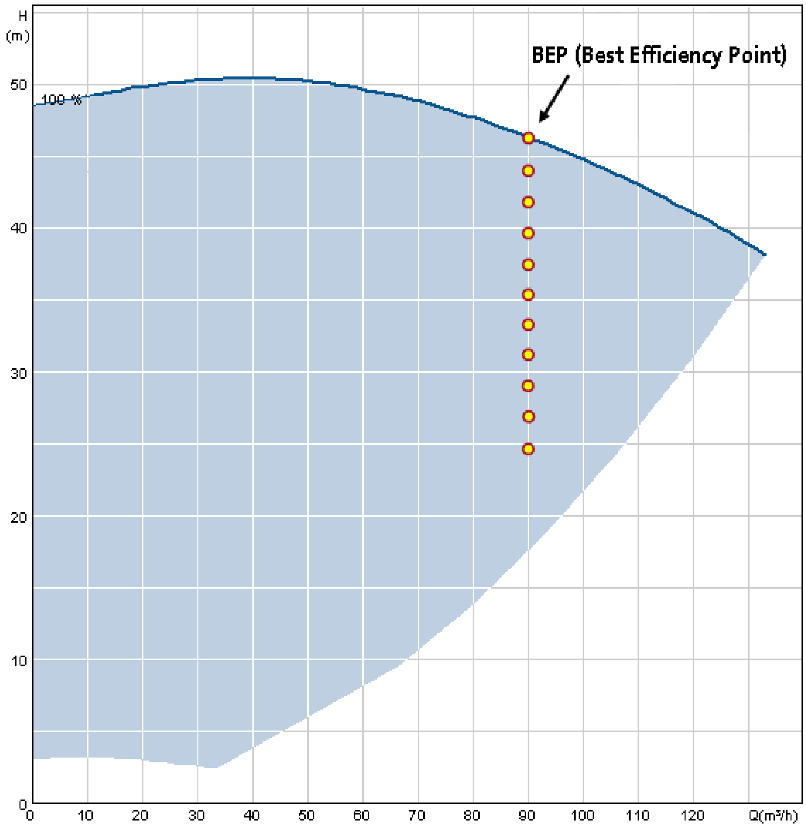
– the calculated proportional pressure control mode with linear influence has been chosen,
– each duty point is met with its appropriate pump,
– the deviation from pump efficiency optimum is up to 3% for each duty point,
– the deviation from the head value of duty point at zero flow rate varies from 0 up to 60%.

During the study, 8 centrifugal pumps of various designs have been analyzed (Grundfos Management A/S, 2011; Wilo SE, 2010).

Evaluation of the change of the efficiency level of centrifugal pumps according to the location of the duty point

Selecting the pumping equipment, it's very important that a duty point is located at the most optimal zone of pump curve. In this case it is possible to achieve the highest possible level of energy efficiency. Of course, the efficiency level drops if centrifugal pumps operate with a lower rotational frequency.

So, it is very crucial to determine the room for improvement of the efficiency level of centrifugal pumps in heating and cooling systems if there are different deviations of duty point location from the head value of the best efficiency point (BEP).



Source: Grundfos Management A/S, 2011

Figure 2. **Deviation of duty point from the head value of the BEP**

The following equation (1) can be used for the determination of pump efficiency level (Giribone P. et al., 2006).

$$\eta = \frac{\rho \bullet g \bullet Q \bullet H}{P_2} . \qquad (1)$$

In this equation (1), η represents the pump efficiency level in %, ρ represents the liquid density in kg m^{-3}, g represents the acceleration of gravity (9.81 m s^{-2}), Q represents the flow rate in m^3 s^{-1}, H represents the head in m and P_2 denotes the shaft power in kW.

Centrifugal pumps of various designs were investigated during the analysis of pumps' efficiency change if there are different deviations of duty point from the head value of the BEP (Figure 2).

There are certain limitations which have been taken into consideration during the investigation. These limitations are as follows:

– the maximum deviation of duty point from the head value of BEP is 75%,
– each analysis of head deviation from its nominal value is met with its appropriate pump.

During the study, 16 centrifugal pumps of various designs have been considered (Grundfos Management A/S, 2011; Wilo SE, 2010).

Results and Discussion

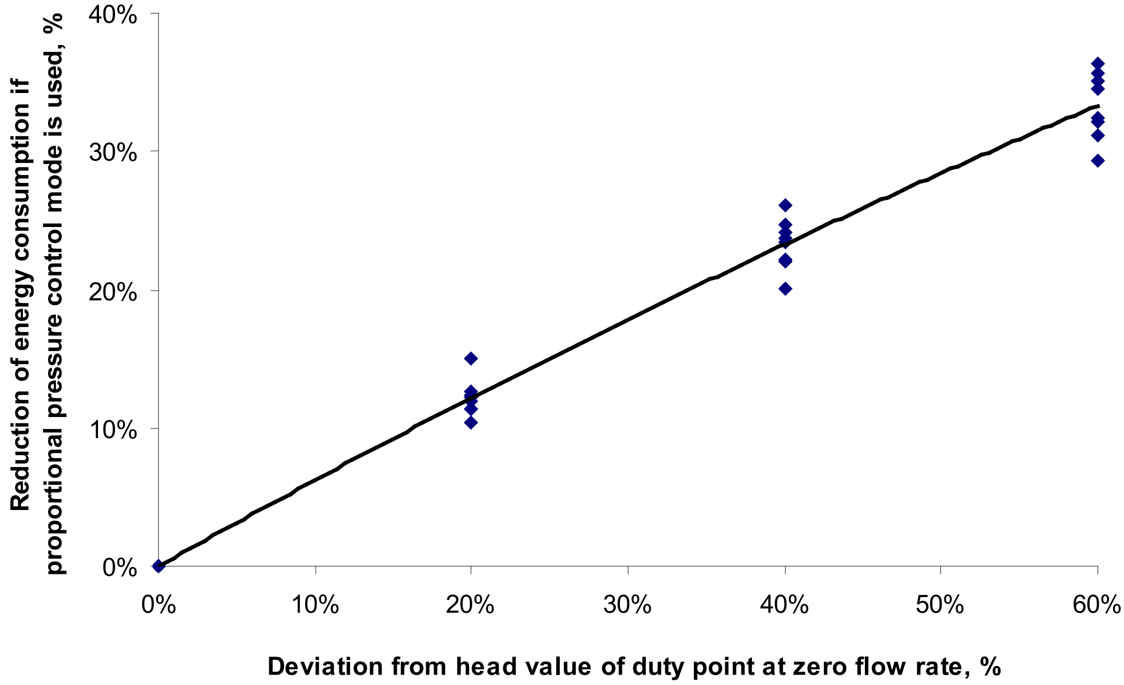
Evaluation of savings' potential if the proportional pressure control mode is applied for circulators in comparison with the constant differential pressure control mode

As a result of the research, the regression equation of the polynomial trend type ($y=\alpha_0+\alpha_1*x+\alpha_2*x^2+\varepsilon$) and the respective coefficient of determination (R^2) has been derived.

$$y = -0.1332 \bullet x^2 + 0.6352 \bullet x - 5 \bullet 10^{-6}$$
$$R^2 = 0.9845 . \qquad (2)$$

In this equation (2), y represents the reduction of energy consumption in % if the calculated proportional pressure control with different deviations from the head value of the duty point at zero flow rate is applied (in comparison with the constant differential pressure control mode) and x denotes the deviation from the head value of the specific duty point at zero flow rate in %.

The equation (2) can be used as a tool for evaluation of the potential reduction of energy consumption at different deviations from the head value of duty point at zero flow. The potential reduction of energy consumption is estimated in comparison with the usage of conventional pump control mode (constant



Source: made by the authors

Figure 3. **Reduction of energy consumption if the calculated proportional pressure control mode with different deviations from the head value of duty point at zero flow rate is applied (in comparison with the constant differential pressure control mode)**

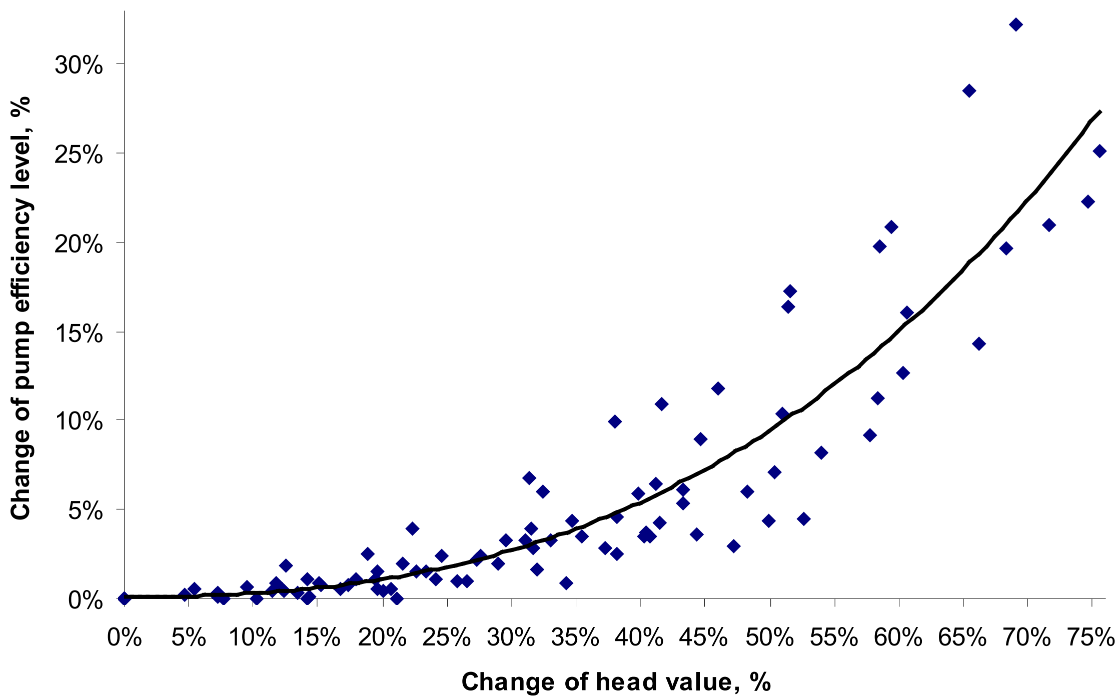


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Figure 4. **Change of centrifugal pump efficiency level at various deviations of head change from its nominal value**

differential pressure control mode) if the value of duty point remains invariable.

The possibility to define precisely the potential reduction of energy consumption of circulators in heating and cooling systems is considerably being decreased with the increase of deviation from the head value of current duty point at zero flow (Figure 3).

Evaluation of the change of the efficiency level of centrifugal pumps according to the location of the duty point

When the change of centrifugal pump efficiency level has been investigated at different values of head change from its nominal value (Figure 4), there has been derived the regression equation with the coefficient of determination (R^2) in the study.

The regression equation of polynomial trend type ($y=\alpha_0+\alpha_1*x+\alpha_2*x^2+ \alpha_3*x^3+ \varepsilon$) has been chosen.

$$y = 0.398 \bullet x^3 + 0.1811 \bullet x^2 - 0.0032 \bullet x + 0.0012 \quad R^2 = 0.8488 \quad . \quad (3)$$

In this equation (3), y represents the change of the pump efficiency level in % and x denotes the change of the centrifugal pump head from its nominal value at a constant value of flow in %.

It's possible to apply the equation (3) as a tool for the evaluation of the decrease rate of centrifugal pump efficiency level at different deviations from the head value of the best efficiency point (Giribone P. et al., 2006).

The possibility to precisely define the change of pump efficiency level is considerably being decreased with the increase of head deviation from the nominal head value of centrifugal pumps if the flow rate is kept constant.

Conclusions

In this research, it has been found that the reduction of annual energy consumption can be achieved up to 33% for circulators with variable speed motors in heating and cooling systems. This reduction of energy consumption is being achieved if the proportional pressure control mode is being applied in comparison with the constant differential pressure control mode. The deviations from the head value of the duty point at zero flow declines up to 60%.

The higher level of the deviation from head value of duty point at zero flow is, the higher level of energy saving is.

In the study, there is also shown that the decrease of pump efficiency level drops up to 3% if the head deviation from the nominal head value of best efficiency point at constant flow is up to 30%.

A slight decrease of pump efficiency level is observed if the deviation from the nominal head value is up to 30%. If the head deviation is above 30% from its nominal value, then the efficiency level of centrifugal pumps rapidly drops.

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