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Evaluation of Effectiveness of Various Control Modes for Variable Speed Centrifugal Pumps in Different Parts of District Heating System

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Abstract: **The goal of this study is the evaluation of effectiveness of various control modes of variable speed centrifugal pumps for use in different parts of a district heating system. For this reason, the regression equations with the coefficients of determination have been derived.**

As a result, the trend of energy consumption reduction has been determined when the proportional pressure control mode is used, in comparison with the constant differential pressure control mode.

The change of the efficiency level of centrifugal pumps of various designs has been also investigated in the article. It has been done at different values of the nominal flow and head when the constant flow control mode is used.

Key words: **Centrifugal pump, control mode, district heating, efficiency.**

INTRODUCTION

Today, with the rapid increase of energy production costs in the world, the increasing attention is paid to improvement of the 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 this energy can be saved up [1].

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

When selecting the pumping technology it is also crucial if the duty point is located at the most optimal zone of the pump's curve, thus achieving the highest possible level of energy efficiency.

With the certain research focused on the evaluation of operation of pumping systems, it is possible to substantially increase the total level of efficiency in district heating systems, thus, contributing to energy saving in the world.

ESTIMATION OF EFFECTIVENESS OF VARIOUS CONTROL MODES OF CENTRIFUGAL PUMPS FOR USAGE IN DIFFERENT PARTS OF DISTRICT HEATING SYSTEM

It is very important to select the appropriate pump control mode [2] and [5] for the respective part of a district heating system. The selection should always be done with a focus on the highest possible level of energy efficiency.

Among a variety of pump control modes the proportional pressure and constant flow control modes [5] have been analysed in the research.

The usage of the proportional pressure control mode has been compared to that of the constant differential pressure control mode [5].

The change of the efficiency level has also been investigated in the study when the constant flow control mode [5] is applied for a certain engineering system.

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

Proportional pressure control mode is generally recommended to be used in systems where the total pressure drop is mostly dedicated to the piping system [6]. Thus, the proportional pressure control is advisable to be used in district heating systems with a relatively long piping network.

Besides that, the proportional pressure control mode should be used, if two-way control valves are installed in the system [2]. The pump will reduce the speed, if the valve is closing. The adjusted head value is being adapted in accordance with the flow variations during the heating process, if the proportional pressure control mode is used [5].

Main circulators (Fig. 1) are normally controlled via constant differential pressure or the proportional pressure control mode (Fig. 2) in district heating systems [5-6]. The proportional pressure control mode is the most efficient control mode for main circulators [5]. Thus, it is crucial to estimate the potential reduction of energy consumption when the proportional pressure control is used, in comparison with the constant differential pressure control.

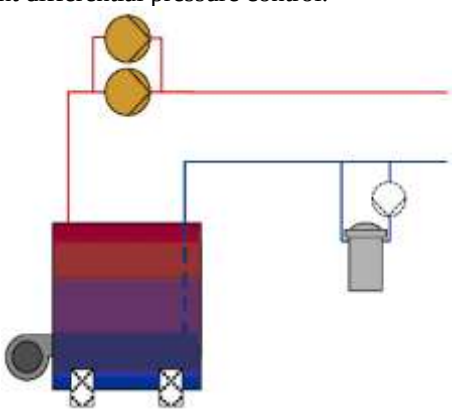

Fig. 1. Main circulators in a district heating system [3]

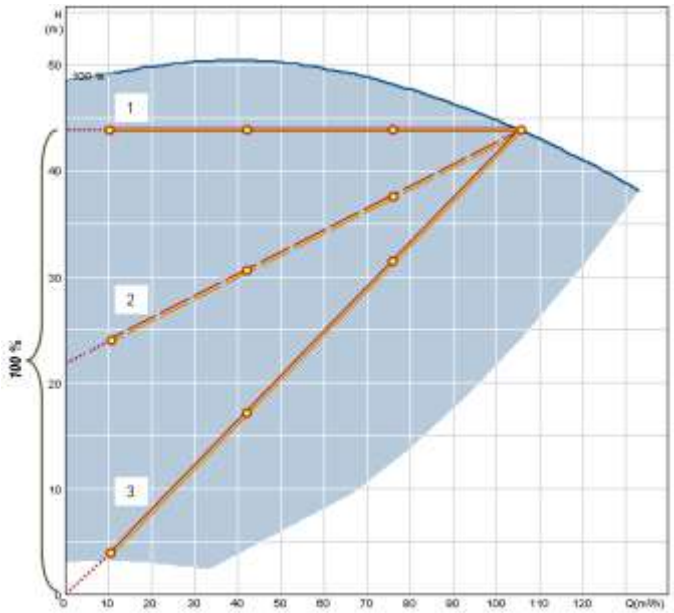

Fig. 2. Control modes of main circulators in district heating systems (1 – constant differential pressure control mode; 2 and 3 – calculated proportional pressure control mode with linear influence) [3]

To analyse the electrical energy consumption, if the proportional pressure control mode with different deviations from the head value of the duty point at zero flow rate is used (Fig. 2), the load profile of the pumping system for a certain part of the district heating system should be taken into account.

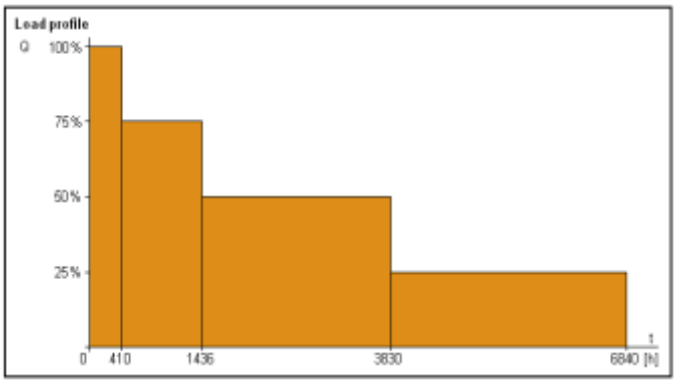

Fig. 3. Load profile of main circulators in the district heating system (Blue Angel Profile) [3]

It has been assumed that the annual operation of the pumping system is 6840 hours and the load profile [9-11] is divided into four parts with different flow values: 100%, 75%, 50% and 25% of the flow rate in the duty point. In its turn, each flow component corresponds to certain duration of the operational time as a part of the total duration of operation per year (according to the Blue Angel profile) [10].

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

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

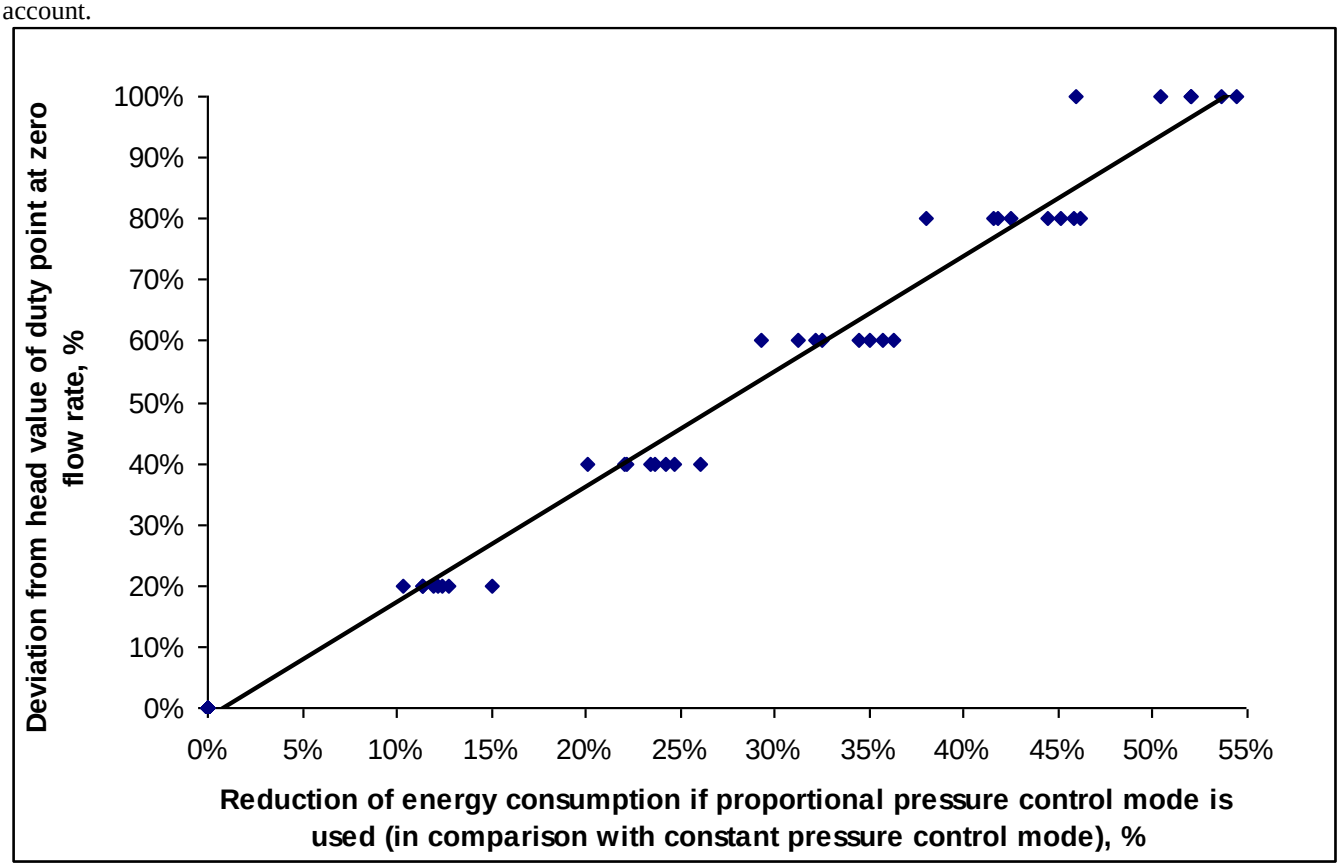

Fig. 4. Reduction of energy consumption, when the calculated proportional pressure control mode with different deviations from the head value of the duty point at zero flow rate is applied (in comparison with the constant differential pressure control mode)

The levels of energy consumption have been compared, if different variants of proportional pressure and constant differential pressure control modes are used (Fig. 2).

During the analysis of the calculated proportional pressure control mode with different deviations from the head value of the duty point at zero flow rate (20%, 40%, 60%, 80% and 100%), calculation of the annual energy consumption for centrifugal pumps of various designs [2-4] has been carried out in the study (Fig. 4).

As a result of the research, the regression equation of the linear trend type ($y = a_0 + a_1 * x + \varepsilon$) and the respective coefficient of determination have been derived.

$$y = 0{,}5212 * x + 0{,}0132$$
$$R^2 = 0{,}9845 \quad (1)$$

In this equation (1), 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 constant differential pressure control) and x denotes the deviation from the head value of the specific duty point at zero flow rate in %.

The regression equation (1) can be used as a tool for evaluation of the potential reduction of energy consumption at different deviations from the head value of the duty point at zero flow rate. The potential reduction of energy consumption is estimated in comparison with the usage of the constant differential pressure control mode, if the value of the duty point remains invariable.

The possibility to define precisely the potential reduction of energy consumption of main circulators is considerably decreased, if the deviation from head value at zero flow rate is increased (Fig. 4).

There are various limitations taken into consideration during calculation of the energy costs [9]. The limitations are as follows:

- Calculated proportional pressure control mode with linear influence has been chosen.
- Each duty point is met with its appropriate pump.
- The deviation from the pump efficiency optimum is up to 3% for each duty point.
- The deviation from the head value of the duty point at zero flow rate varies from 0 up to 100%.

During the study, eight centrifugal pumps of various designs have been analysed [3-4].

Evaluation of effectiveness of constant flow control mode applied for flow filter pumps

Flow filter pumps (Fig. 5) are normally used for improvement of the quality of district heating water in district heating systems. These pumps are usually controlled via the constant flow control mode [5-7].

The operational principle of the constant flow control is as follows: the flow rate is kept constant independently of the head value change (Fig. 6).

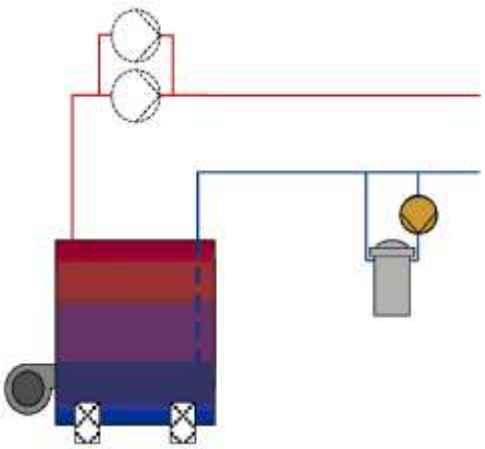

Fig. 5. Flow filter pump in a district heating system [3]

This control mode can be realised by keeping the differential pressure constant over the hydraulic resistance with the known value of the head loss [5] and [8].

It is advisable to determine the level of pump efficiency, if the constant flow control mode is applied for flow filter centrifugal pumps in a district heating system. The following equation (2) can be used for determining the pump efficiency level [1-2].

$$\eta = \frac{\rho * g * Q * H}{P_2} \quad (2)$$

In this equation (2), 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, H represents the head in m and P_2 denotes the shaft power in kW.

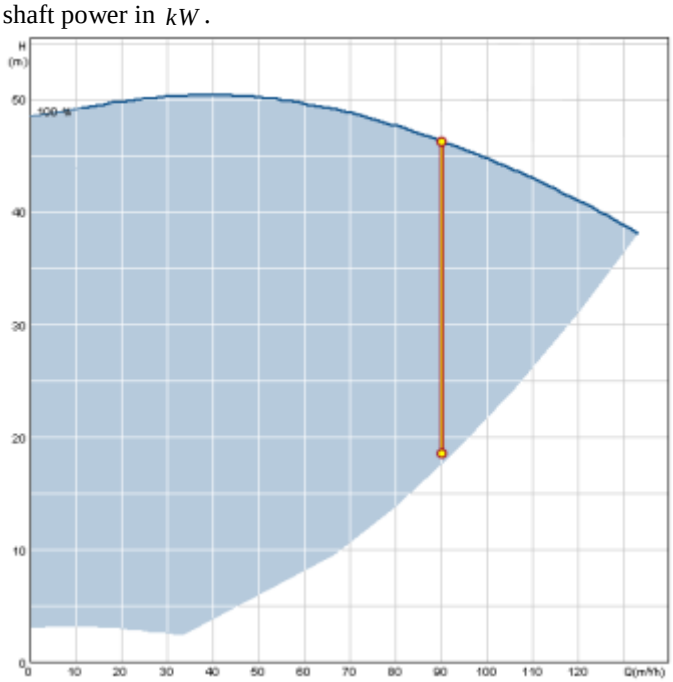

Fig. 6. Constant flow control mode of flow filter pumps in district heating systems [3]

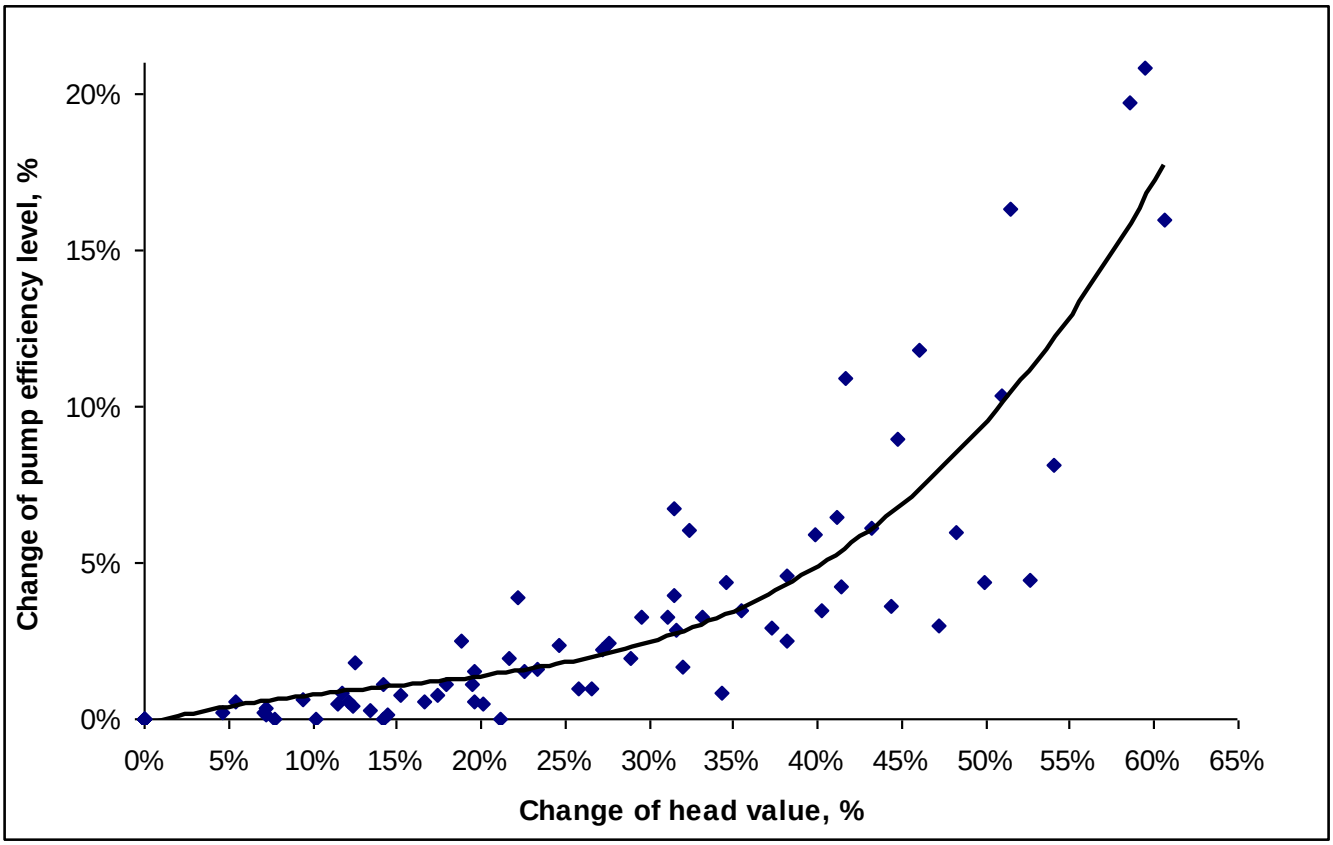

Fig. 7. Change of centrifugal pump efficiency level at different values of the head change from its nominal value

When the change of the pump efficiency level has been investigated at different values of the head change from its nominal value (Fig. 7), the regression equation with the coefficient of determination has been derived in the study. The regression equation of the polynomial trend type ($y = a_0 + a_1 * x + a_2 * x^2 + a_3 * x^3 + \varepsilon$) has been chosen.

$$y = 1{,}4231 * x^3 - 0{,}6108 * x^2 + 0{,}1431 * x - 0{,}0021 \quad (3)$$
$$R^2 = 0{,}7954$$

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 in %.

It is possible to apply the regression equation (3) as a tool for evaluation of the decrease rate of the centrifugal pump efficiency level at different deviations from the head value of the best efficiency point (BEP) [1].

The possibility to precisely define the change of the pump efficiency level is being considerably decreased with the increase of the head deviation from the nominal head value of centrifugal pumps, if the flow rate is kept constant (Fig. 7).

Having analysed the efficiency level of centrifugal pumps, if the constant flow control mode is used, the certain load profile should be taken into account in order to evaluate the average annual decrease of the efficiency level.

It has been assumed that the annual operation of the pumping system is 6840 hours [10] and the load profile is divided into four parts with different head values: 100%, 78%, 59% and 38% from the head value of the best efficiency point. In its turn, each head component corresponds to certain duration of the operational time as a part of the total duration of the operation per year.

Each head component corresponds to certain duration of the operational time in the following way (Fig. 8):

100% -> 25%,
78% -> 25%,
59% -> 25%,
38% -> 25%.

As duration of the operational time is the same for each of the four head components, the average annual decrease of the efficiency level is 6 %.

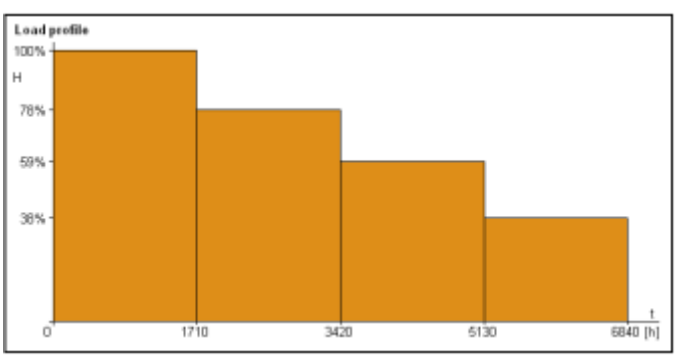

Fig. 8. Load profile for flow filter pumps in district heating systems [3]

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

- The constant flow control mode has been analysed at different deviations from the head value of the best efficiency point (BEP).
- The maximum deviation from the head value of the best efficiency point is up to 62%.
- The analyses have been realized with different centrifugal pumps.

During the study 12 centrifugal pumps of various designs have been considered [3-4].

CONCLUSIONS

In this research, it has been found that up to 51% reduction of the annual energy consumption can be achieved for main circulators in district heating systems. This reduction of energy consumption is achieved, if the proportional pressure control mode is applied, in comparison with the constant differential pressure control mode. The deviations from the head value of the duty point at zero flow rate declines up to 95% (the pressure drop over the control valves is assumed as 5% of the total pressure drop in the system).

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

It's also shown that the pump efficiency level drops up to 19% for flow filter pumps in district heating systems. This drop of the efficiency level is achieved, if the head deviation from the nominal head value of the best efficiency point is up to 62% (according to the maximum deviation from the nominal head value used in the load profile for the calculation).

A slight decrease of the 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, the efficiency level of centrifugal pumps rapidly drops.

RECOMMENDATIONS

It is important to estimate the potential savings for main circulators in district heating systems, if the traditional constant differential pressure control mode is used.

To this effect, the following regression equation ($y = 0{,}5212 * x + 0{,}0132$), derived in this research, can be used for estimation of the potential reduction of annual energy consumption, if the proportional pressure control mode is applied, in comparison with the constant differential pressure control mode.

It's also advisable to estimate the effectiveness of the constant flow control mode applied for flow filter pumps in district heating systems.

This can be done by using the regression equation ($y = 1{,}4231 * x^3 - 0{,}6108 * x^2 + 0{,}1431 * x - 0{,}0021$).

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Deniss Piļščikovs, Egīls Dzelzītis. Mainīga ātruma centrbēdzes sūkņu vadības metožu energoefektivitātes novērtējums izmantošanai dažādās centralizētās siltumapgādes sistēmas daļās

Pētījuma mērķis ir energoefektivitātes uzlabošanas potenciāla novērtējums, ja proporcionālā spiediena vadības metode tiek pielietota galveno tīkla sūkņu vadībai, kā arī ekspluatācijas efektivitātes novērtējums, ja konstantas plūsmas vadības metode tiek pielietota plūsmas filtra sūkņu vadībai centralizētajos siltumapgādes tīklos.

Energoefektivitātes uzlabošanas potenciāla novērtējums galvenajiem tīkla sūkņiem tiek realizēts salīdzinot proporcionālā spiediena vadības metodi ar tradicionālo konstanta diferenciālā spiediena vadības metodi, ja darba punkts un slodzes profils paliek nemainīgs. Proporcionālā spiediena vadības metode tiek realizēta pie dažādām novirzēm no noteikta darba punkta celšanas augstuma vērtības pie nulles patēriņa. Tajā pašā laikā plūsmas filtra sūkņu energoefektivitātes līmeņa novērtējums tiek realizēts ņemot vērā dažādas celšanas augstuma novirzes no nominālā celšanas augstuma vērtības.

Centrbēdzes sūkņu analīzes gaitā tika iegūts attiecīgs regresijas vienādojums, ar kuru palīdzību ir iespējams novērtēt enerģijas patēriņa samazinājuma potenciālu galvenajiem tīkla sūkņiem, ja pašreizējā situācijā tiek pielietota tradicionālā konstanta diferenciālā spiediena vadības metode. Bez tam tika iegūts regresijas vienādojums, kas apraksta centrbēdzes sūkņu efektivitātes līmeņa samazinājumu atkarībā no dažādām novirzēm no sūkņa nominālā celšanas augstuma vērtības.

Pētījuma gaitā tika veikti vairāki patērētās elektroenerģijas aprēķini pie attiecīgā slodzes profila dažādas konstrukcijas centrbēdzes sūkņiem. Visiem aprēķiniem tika izmantots „Zila Eņģeļa" slodzes profils (Blue Angel Profile). Tika konstatēts, ka palielinot celšanas augstuma novirzes vērtību no noteikta darba punkta vērtības pie nulles patēriņa realizējot proporcionālā spiediena sūkņu vadību, ir noteikta tendence energoefektivitātes uzlabošanas potenciāla palielināšanai galvenajiem tīkla sūkņiem. Pētot centrbēdzes sūkņu efektivitāti, ja tiek pielietota konstantas plūsmas sūkņu vadības metode, tika noteikta efektivitātes līmeņa izmaiņas tendence.

Денис Пильщиков, Эгилс Дзелзитис. Оценка энергоэффективности методов управления центробежными насосами переменной скорости для эксплуатации в различных частях системы централизованного теплоснабжения

Целью публикации является оценка потенциала улучшения энергоэффективности при использовании метода управления пропорциональным давлением для управления главными сетевыми насосами, а также оценка эффективности эксплуатации при использовании метода управления константным потоком для управления насосами фильтрации потока в сетях централизованного теплоснабжения.

Оценка потенциала улучшения энергоэффективности для главных сетевых насосов осуществляется путем сравнения метода управления пропорциональным давлением с традиционным методом управления константным дифференциальным давлением, если значение рабочей точки и профиль нагрузки являются неизменными. Метод управления пропорциональным давлением осуществляется при разных отклонениях от величины напора определенной рабочей точки при нулевом расходе. В то же время оценка уровня энергоэффективности насосов фильтрации потока осуществляется при учете разных отклонений напора от величины номинального напора.

В процессе анализа центробежных насосов было получено соответствующее регрессивное уравнение, с помощью которого можно оценить потенциал понижения потребления электроэнергии главными сетевыми насосами, если в настоящий момент используется традиционный метод управления константным дифференциальным давлением. Кроме того, было получено регрессивное уравнение, которое описывает понижение уровня эффективности центробежных насосов, в зависимости от разных отклонений от величины номинального напора насоса.

В процессе исследования было выполнено множество расчетов потребления электроэнергии при соответствующем профиле нагрузки для центробежных насосов различной конструкции. Было констатировано, что при увеличении величины отклонения напора по отношению к определенной рабочей точке при нулевом расходе, реализуя метод управления пропорциональным давлением, наблюдается определенная тенденция увеличения потенциала улучшения энергоэффективности для главных сетевых насосов. Исследуя эффективность центробежных насосов фильтрации потока, при использовании метода управления константным потоком, была определена тенденция изменения уровня эффективности.