POWER EFFICIENCY IMPROVEMENT OF HEATING SUBSTATION USING PUMP MOTOR SPEED RATE REGULATION

Dmitrij Shirkin, Ivars Rankis
Riga Technical University, Latvia
shirkini@inbox.lv

Abstract. The paper presents an implementation example for heating system efficiency improvement using fluent speed regulation of heating pumps instead of pipes throttling. The method of the pump motor speed regulation lets us cut down electrical energy consumption and significantly improve the regulation characteristics during dynamical heating load change.

Keywords: heating system, throttling, pump rate, frequency, temperature difference.

Introduction

Heating systems consume over 45 % of the energy produced in the world. Most heating systems operate under the control of weather compensation controllers. Today weather compensation controllers use mechanical throttling of pipes as a regulation method. The efficiency of the existing heating systems can be improved by introducing adjustable speed regulation of the pump motor.

Heating system substation

Basically the heating substation electrical system consists of a weather compensation controller, outdoor and flow temperature sensors, circulation pump and motorized control valve (see Fig. 1). Weather compensation controllers control the heating system flow temperature on dependence of the outside temperature. Controllers calculate the flow heat agent temperature set-point from the current outside temperature and control a motorized valve by changing the valve position from totally opened with maximum flow to totally closed position with minimum flow thus automatically controlling the temperature. The valve motor is controlled discrete by means of thyristors or analogue control signals [1].

The nominal power of the heating system circulation pump is calculated to compensate the coldest five-day-period average temperature, for Riga the temperature is -20.7 ºC. The duration of the cold season in Riga is 203 days and the air temperature can go up to +7.0 ºC [2]. Meanwhile, the heating system circulation pump is loaded on its nominal electrical power all heating season long, and the existing heating systems do not take into account the circulation pump electrical power saving potential.

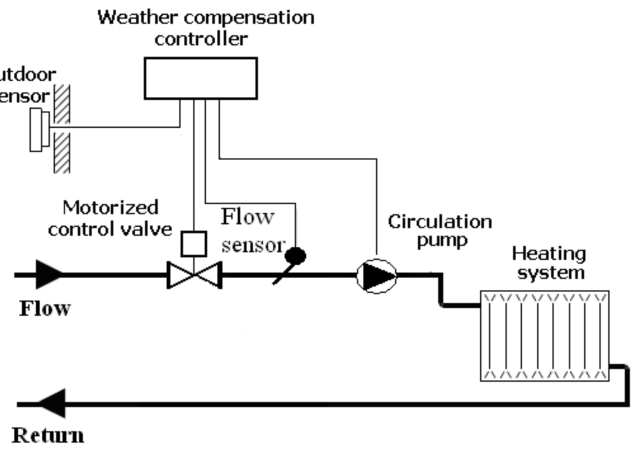

Fig. 1. **Principal scheme of heating substation**

Pump regulation by throttling

The pump and heating system curves describe the relation between the pump and system flow rate (*Q*) and head or pressure (*H*), the curves intersection display the pump actual operation point (see Fig. 2). The electrical power consumption of the pump is defined by the formula [3]:

$$P = \frac{Q * H * g * \rho}{\eta * 3.6 * 10^6} \quad , \tag{1}$$

where P – electrical power, kW;
Q – flow rate, $m^3 \cdot h^{-1}$;
H – head, m;
g – free fall acceleration, 9.81 $m \cdot s^{-2}$;
ρ– density of fluid, $kg \cdot m^{-3}$;
$3.6 \cdot 10^6$ – conversion factor for kW;
η – complex efficiency grade, which is effected by the motor efficiency (about 0.85) and pump efficiency (in the middle part of the range between zero and maximum head for centrifugal pumps about 0.5-0.8).

Modern heating systems include regulation valves, for instance, heater thermostatic valves and balancing valves. When the regulation valves are closed the heating load and thus the flow are decreased, this regulation method can be described as throttling. During throttling the flow is reduced from Q_{max} to Q_{red} by creating head losses ΔH on valves, thus shifting the curve, and changing the performance point of the pump from A1 to A2 it is obvious, that on totally closed valve power losses being maximal the power consumption of the pump due to the losses remains practically close to maximum. During throttling the power is consumed inefficiently.

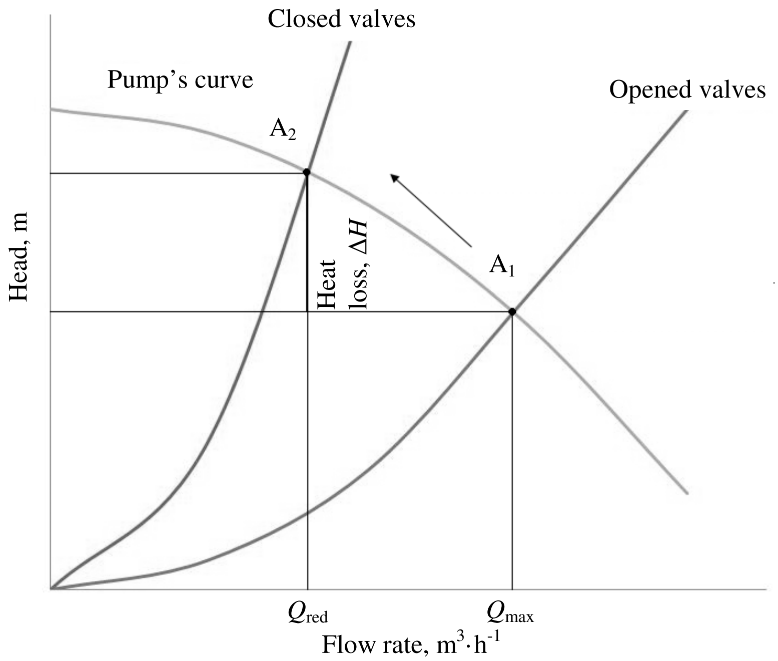

Fig. 2. **Pump and heating system curves at throttling**

Pump regulation by motor speed rate change

A more effective control method should be to control the flow not mechanically by throttling, but directly by control of the circulation pump rotation speed rate.

The circulation pump has asynchronous motor and its rotation speed rate (n) can be controlled by electrical frequency (f) [4]:

$$n = \frac{60 f (1 - s)}{p} , \tag{2}$$

where n – speed rate, rpm;
f – frequency, hz;
p – pole number;
s – slip, which is about 0.02-0.05.

In Fig. 3 the relation between the head (*H*) and flow rate (*Q*) at variable speed regulations of the pump motor, i.e., at changing the frequency is presented.

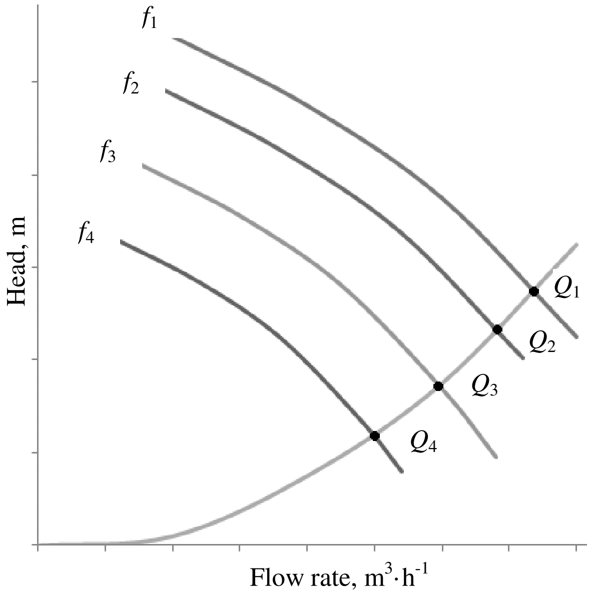

Fig. 3. **Flow control by motors frequency change**

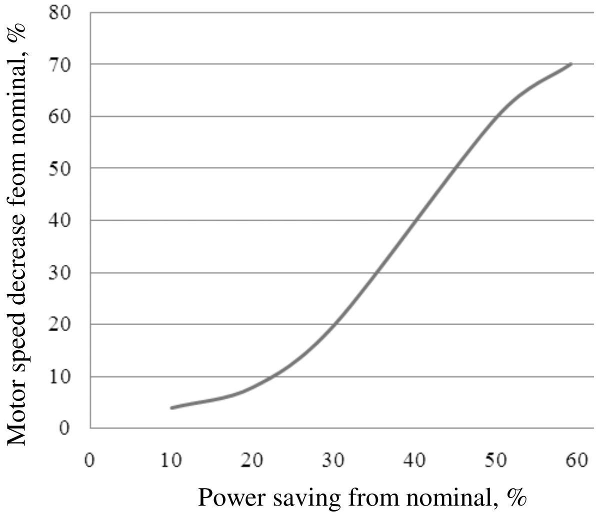

Fig. 4. **Electrical power saving by pumps motor speed decrease rate from nominal ones**

If the frequency is lower, then both *H* and *Q* are decreased. The change of the power consumption of the pump can be expressed as [5]:

$$\frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3, \quad (3)$$

where n_1 – higher speed rate, rpm;
n_2 – lower speed rate, rpm;
P_2 – electrical power at lower speed n_2, kW;
P_1 – electrical power at higher speed n_1, kW .

For instance, if we change the pump speed rate from 1500 rpm to 1350 rpm, i.e., the speed of the pump decreased by 10 %, then the electrical power decreases by 27 %. Figure 5 describes connection between the electrical power saving potential (W) by the pump motor speed decrease rate from nominal ones $n1/n2$ (see Fig. 4).

At regulation asynchronous motor magnetization the current must be kept constant, i.e., to keep frequency proportional to voltage on stator winding. That is why it is essential to change voltage, when changing the frequency, i.e., to keep *U/f* constant.

Dynamical heating load change by regulation of throttling valves, affects flow rate of the heating system. An efficient regulation method of the circulation pump, is the pump frequency control from the heating system flow rate, the pump performance point A3 (see Fig. 5). The evaluation of power savings (Δw) by frequency converter integration into the heating system and head reduction by the pump frequency change from flow rate change can be described as (4):

$$\Delta W = (1 - \frac{H_2}{H_3}) * 100, \quad (4)$$

where H_2 – pump head at closed valves, m;
H_3 – pump head at regulation by flow rate, m;
Δw – electrical power savings, %.

Frequency control by flow rate requires flow-meter integration into system what complicates and raises the price of the heating system.

Momentary heating load change can be described as temperature difference ΔT. That is why more efficient method would be the pump frequency control by ΔT (see Fig. 6).

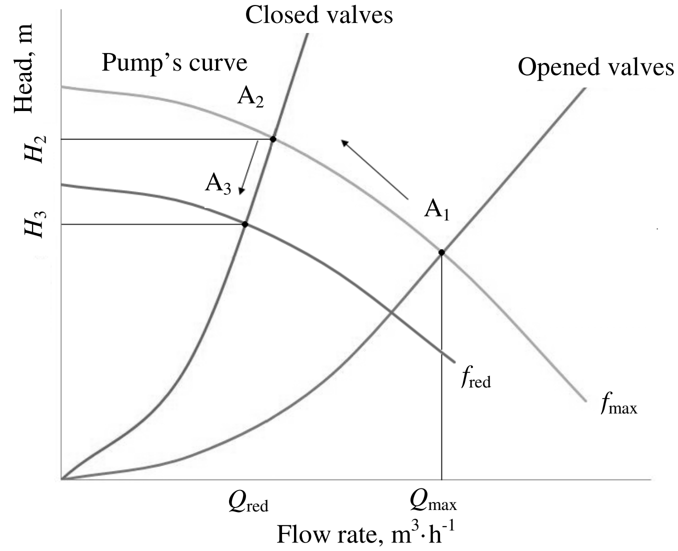

Fig. 5. **Head reduction at frequency control by flow rate compared to the one at throttling**

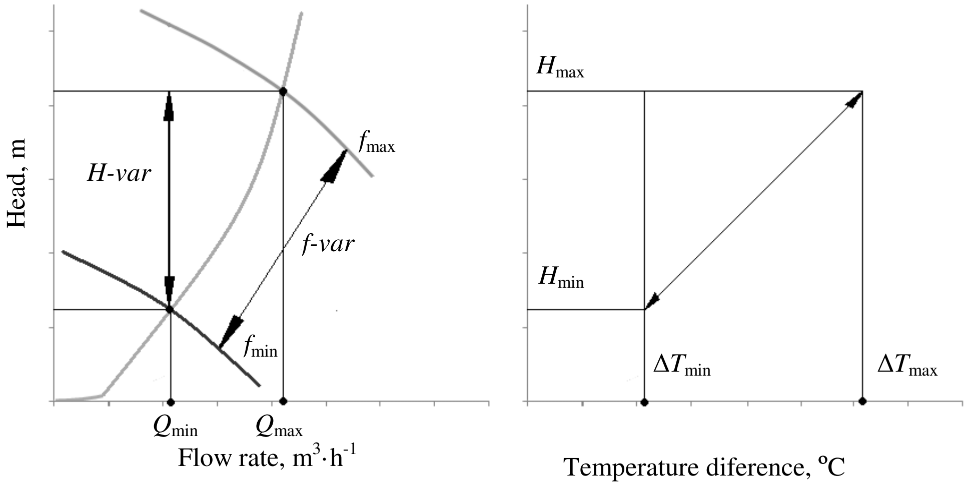

Fig. 6. **Pump control by temperature difference ΔT**

Conclusions

The existing substation systems control the circulation pump inefficiently by loading the pump on its nominal electrical power during the whole heating season.

The heating system substation regulation by frequency control results in electrical power consumption rate reduction up to 60 % on dependence of the speed decrease rate.

The most efficient control method of the heating circulation pump in the heating system with dynamically changing heating load is control by the flow and return temperature difference ΔT.

References

1. Pirkov V. Современные тепловые пункты. Автоматика и регулирование.- Kiev: Данфосс TOB, 2007, 450 p.
2. Kreslinš A., Kigurs J. Eku apkures sistemas. – Riga: Avots, 1983, 146 p.
3. Nagla J., Saveļjevs P., Ciemiņš R. Siltumtehniskie pamati.- Riga: Zvaigzne, 1981, 356 p.
4. Mohan N., Undeland T., Robbins W. Power Electronics: Converters. Application and Design. NY: John Wiley and sons, 1989, 667 p.
5. Greivulis J. Elektriskās piedziņas teorētiskie pamati. Riga, Riga Technical University, 1989, 456. p.