Water flow adjustment of pumps in heating stations

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Abstract. *In urban heating stations the heat agent circulation between the energy source and consumers is assured by pumps, which take part to the energy consumption of the system in the operation period. The number, the position, and the technical characteristics of these pumps are established according to the chosen type of the heating system, the thermal power and the operating regime. Using variable rotation speed pumps it is possible to have a continuous control over the water pressure according to the thermal load at a certain moment. In this paper are presented and analyzed some optimization solutions of pumps operation in urban heating stations from energy point of view.*

Key words: heating stations, energy saving, variable speed centrifugal pump, variable frequency drives

1. Introducere

Heating stations are dimensioned to provide the consumers energy need in the coldest period of the year. However, most of the energy need is much lower than the designed value of the heating station thermal load. Consequently the primary agent flow must be reduced most of the time from heating season. This flow variation can be carryed out for constant speed of centrifugal pup using following methods: by-passing a part of the water discharge (the pump operates at the same operation point and the absorbed power remains constant); by introducing a supplementary pressure loss (ΔH), using a regulating valve (the operation point is heading towards left in H-Q diagram) [1-6]. Another method is to operate with variable rotation speed pumps. [4-8]

2. Thermal load of the heating stations

In Figure 1, the yearly distribution of the daily average outdoor temperature is presented. The diagram points out the fact that, in the year, the lowest temperatures represent about 5 %. Thus, if the heating station is dimensioned to cover the maximal energy need, then 95 % on the year the station is over dimensioned. At the same time, it can easily be seen that approximately 40 % of the year the average temperature is higher than +15 °C. Thus, 40 % of the year the thermal energy provided by heating station is used only to prepare the domestic hot water, which needs only a small part of the installed capacity of the heating station.

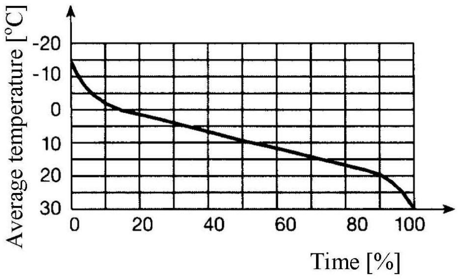

Fig.1 Average external air temperature in time

At constant difference between the forward and return temperatures of the warm water, the delivered energy do not varies proportionally with the discharge. Generally, at constant forward temperature the return temperature is lower when the required heat decreases.

In Figure 2 is presented the relative produced heat quantity depending on the relative discharge at constant forward temperature of the warm water. When the water discharge is reduced, for example at 60 % of the initial value, the produced heat quantity decreases only at 85 % of the initial value, because the water-cooling is increased.

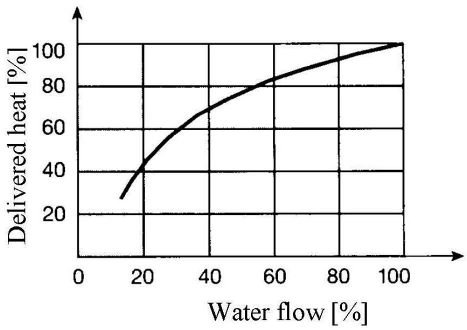

Fig. 2 Relative amount of heat delivered in time
for constant forward temperature

The main goal in operating a heating system is to assure the consumers with the required heat flow according to outdoor climatic parameters. Thus, the heating system is provided with a regulation system, which can be qualitative, quantitative or mixed.

The quantitative adjustment requires a variation of the flow during the operation, the warm water parameters being constant. It can be done by:

– pumps with different technical characteristics (flow, pumping head);

– variable rotating speed pumps.

The assurance of the required heat flow, demand an adjustment in the distribution system between the heat source and consumers. Depending on the applied methods, important variations of the energy consumption are obtained. In Figure 3 the energy consumption curves for different adjustment methods are presented.

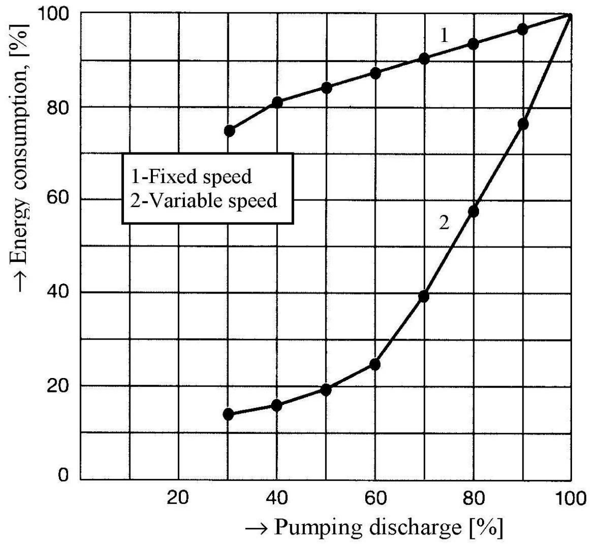

Fig.3 Energy consumption for variable flow

The variation of energy consumption depends on the global efficiency of the heating system, the configuration of the distribution system, the operation point and the type of the adjustment equipments.

Analyzing the presented curves one can observe that the energy consumption in the case of regulating valves is higher than the energy consumption in the case of variable rotation speed pumps.

The throttling valve control method of reducing water flow is presented in Figure 4.

The characteristic curve of the system $H_{r1}=f(Q)$ establishes the nominal pump operation point in F, according to H_F pressure head, Q_F water discharge and the specific pumping energy w_{pF} [5].

Shutting partially the pumps outlet the systems characteristic curve becomes $H_{r2}=f(Q)$ and, according to new operation point the water discharge will decrease to Q_o, the pumping head will increase to H_o, the specific pumping energy will decrease to $w_{po}=w_{p\min}$ and the efficiency of the pumps will increase from η_F to η_o.

The higher pumping head will lead to a lower hydraulic efficiency of the system and finally to a lower global efficiency. From this reason the water discharge regulation with regulating valves is avoided in practice [3], [7]. However, examining the specific pumping energy curves w_p, one can be observe that the global efficiency of the system increases even when the hydraulically efficiency is decreasing. This is possible when the regulation is done under the point O that corresponds to the minimal specific pumping energy, on the characteristic curve of the pump. If the regulation is made above the point O by increasing the pumping head, then the specific pumping energy increases, leading thus to an increase of the energy consumption.

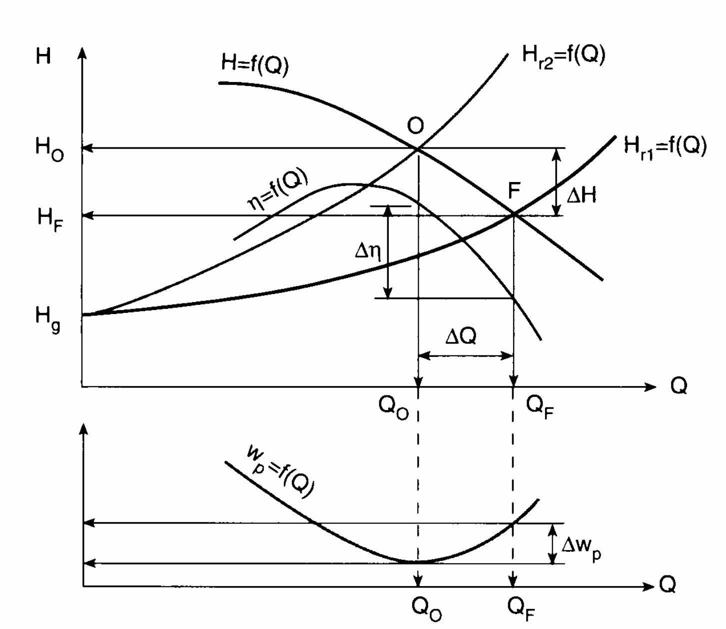

Fig.4 Flow variation by throttling valve

Thus, the operation diagram of a centrifugal pump can be separated in two areas divided by the operation point corresponding to the minimal pumping energy. The regulation is to be avoided when the pumping head is higher and the regulation is recommended when the pumping head is lower than the pressure corresponding to point O.

Although the regulation of water discharge using regulating valves can lead to higher energy efficiency of the heating system when the nominal pumping head is lower than the optimal value, this procedure have the followed disadvantages:

– an increased wear of regulating valves shutting elements;

– noise, vibration and hydraulic impacts with negative effects in the system;

– low operation reliability of the pumps.

The best procedure to obtain variable heat flow is the use of variable rotation speed pumps. The flow regulation (Fig. 5) is done due to the changing of the pump characteristic curve *H* (at different rotation speed n_1 and n_2) on the fixed characteristic curve of the system H_r. The operation point F_2 corresponds to the reduced pumping head H_{F2}.

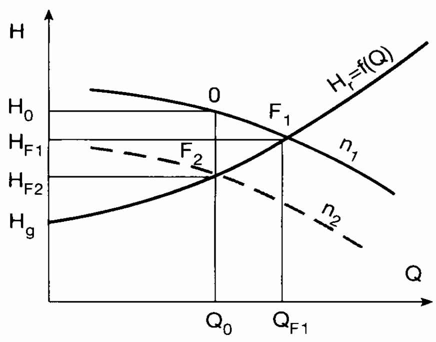

Fig. 5 Variable speed centrifugal pump operation

The characteristics of the pumps variable rotation speed could be expressed with the followed similitude relations:

$$\frac{Q_1}{Q_2} = \frac{n_1}{n_2} \quad (1)$$

$$\frac{H_1}{H_2} = \left(\frac{n_1}{n_2}\right)^2 \quad (2)$$

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

The power demand P, in kW, at certain rotation speed is given by:

$$P = \frac{\gamma Q H_p}{1000\eta} = 3600 w_p Q \quad (4)$$

where: γ is the specific weight of the water, in N/m^3; Q – the pumping discharge, in m^3/s; H_p – the pumping head corresponding to the operation point, in m; η – the global efficiency of the pumping plant; w_p – the specific pumping energy, in kWh/m^3.

The efficiency dependence of the rotation speed is given by the relation (5), thus, one can determine the efficiency η_2 in operation point F_2 according to the rotation speed n_2 in function of η_1 and n_1.

$$\eta_2 = 1 - (1 - \eta_1)\left(\frac{n_1}{n_2}\right)^{0,1} \quad (5)$$

In fact, at the majority of the pumps and especially at the big ones, the efficiency variation can be neglected for a variation of rotational speed of 1/3 from the nominal value.

In Figure 6 are presented the variation curves of H, Q, P and η for centrifugal pumps depending on rotational speed n. It can be observed that a reduction with 20 % of the rotational speed will lead to the reduction of power demand with 50 %, at constant pump efficiency. Thus, results the possibility to reduce the pumping energy consumption by using variable rotational speed pumps. One of possible ways to achieve is variable frequency drives (VFDs).

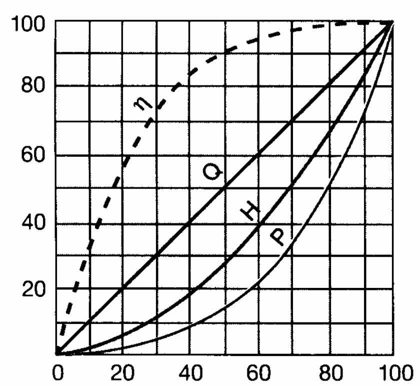

Fig. 6 Variation of centrifugal pump parameters with load

In certain countries, the use of the electronically driving methods of electrical engines the variation of rotation speed was extended up to industrial scale [1]. The variation of rotational speed of the electric driven pumps can be carried out with: frequency converters or variable frequency drives (VFDs), continuous current engines, voltage control and mechanical drives.

3. Throttling control valve versus variable speed drive for flow control

3.1 Comparative energy analysis of the adjustment process

The energy efficiency of the above presented regulation methods are analyzed based on the operation regime of a pump for different values of the rotation speed (Fig. 7).

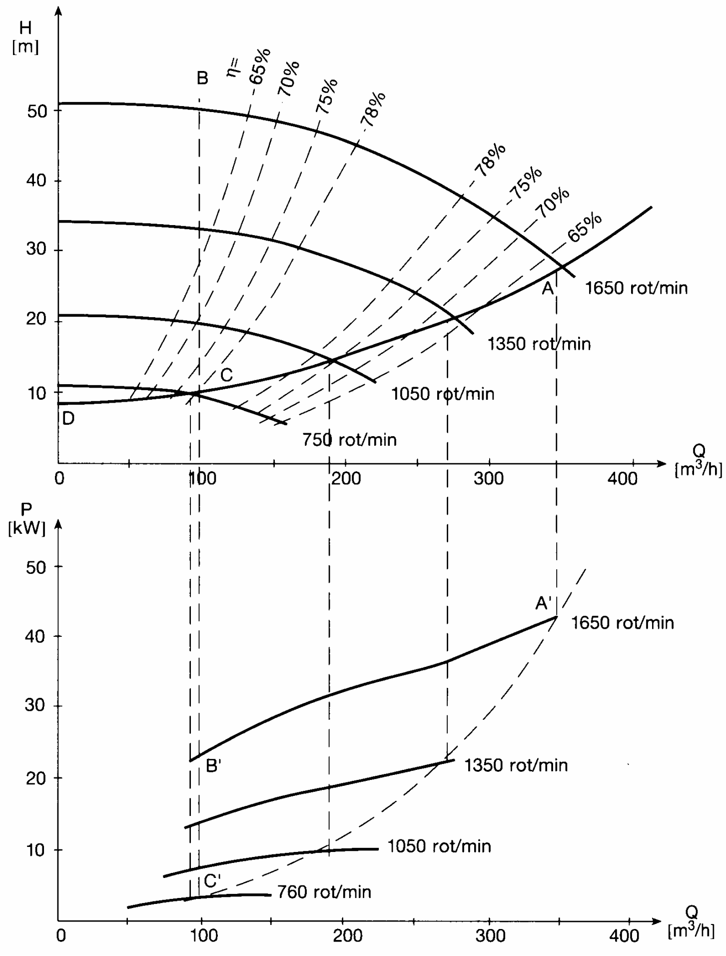

Fig. 7 Energy consumption for different flow with VFDs

If the maximal load is 350 m^3/h at the pumping head of 28 m, the absorbed power is 42,5 kW. If the water discharge is reduced to flow rate of $100 m^3/h$ using throttling valve, the pumping head increases up to 50 m and the shaft power will be 23 kW at a constant rotational speed of 1650 rot/min. The operating curves are marked with A-B on the *H*-*Q* and with A'-B' on the power diagram.

The relation with the shaft absorbed power is presented with the dashed curve. Thus, it is possible to compare the absorbed power, in the case of adjust with valves and with variable rotational speed pumps. Consequently, if the yearly distribution is known the energy consumption can be determined.

The numerical results, based on the characteristic curves from Figure 7, are presented in Table 1.

From the results of the analysis, it can be seen a yearly energy consumption decrease from 275064 kWh to 124173 kWh, by rotational speed variation. The energy saving is about 151000 kWh which represents about 55 %.

Table 1

The absorbed power and the energy consumption using adjusting valves and rotational speed variation

Discharge	Distribution		Regulating valves		Variable speed	
Q [m^3/h]	%	Hours	Power P [kW]	Energy W [kWh]	Power P [kW]	Energy W [kWh]
0	1	2	3	4	5	6
350	5	438	42,5	18615	42,5	18614
300	15	1314	38,5	50589	29,0	38106
250	20	1752	35,0	61320	18,5	32412
200	20	1752	31,5	55188	10,0	17520
150	20	1752	28,0	49056	6,5	11388
100	20	1752	23,0	40296	3,5	6132
Total	100	8760	–	275064	–	124173

3.2 Prediction of energy savings with variable speed drives in a heating station

The heating stations from Timisoara are being modernized in order to increase their efficiency and to be less harmful to the environment. Before this modernization be accomplished, the operation of one pump used in heat supply period was analyzed.

The measured parameters of the pump were: hot water flow rate Q and water pressure. The measurements were made every hour, during several days in a month with large variations in flow of hot water, April. Knowing water temperature, for every hour were calculated the power requirements in two cases: throttle control with a valve and reducing rotational speed with variable frequency drives.

The characteristics of the pomp are: type: TD 500-400-750; flow rate: 3150m^3/h; pumping head: 70m. The engine characteristics are: type: MIB-X 710Y; power: 800 kW; rated current: 94A; Voltage: 6000 V; rotational speed: 995 revolutions per minute-rpm; cosφ= 0.87; mass: 6000 kg.

Heat flow depends on the temperature of external air and is influenced by the temperature of the reverse network. The operational water flux of the pump was lower of course than the nominal one, for which the pump was built. In order to achieve the desired flow rate, as provided in the chart control it was necessary to act to close the valve mounted on the pump outlet. Thus reducing the water flow, the head of the pump becomes higher than that from characteristic curves at the same flow. In Figure 8 are presented characteristic curves for that type of pump: $H=f(Q)$; $\eta=f(Q)$; $P=f(Q)$.The power absorbed by the electric engine is also lower. For each hour, authors calculated necessary power P_t for this case of throttle control of the network, with relation (4).

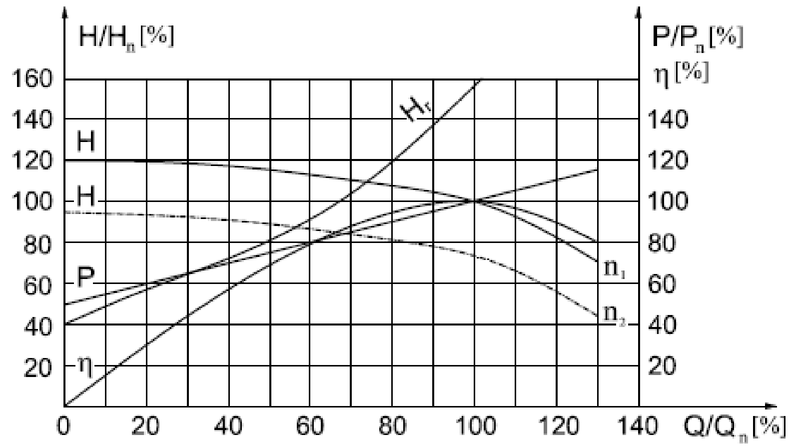

Fig. 8 Characteristic curves of the pump

For each day the authors calculated also the daily power used. The pump necessary power P_2, when the motor use frequency convertor, is obtained from affinity laws (1) and (3):

$$P_2 = P_1 \cdot \left(\frac{Q_2}{Q_1}\right)^3 \tag{6}$$

in which: P_1 is the necessary power of fixed speed pump for operating point Q_1 = 3150 m^3/h and H_1 =70 m.

The relationship between rotation speed of the pump and electric energy frequency is:

$$n = \frac{60 \cdot \nu}{p}$$

where: n is the rotational speed; ν-energy frequency; p-number of pole pairs of the engine.

If is necessary to change rotational speed, could be changed number of pole pairs of the engine or energy frequency. The second case is easily achievable.

In Figure 9 are plotted P_1, P_t and P_2 for the whole operating period from April. The average ratio between P_2 and P_t is 0.67. This means a reduction of electric energy applying adjustment method by variable rotational speed using VFDs compared with throttling valve control of 32.8%, i.e. 2835.2 kWh.

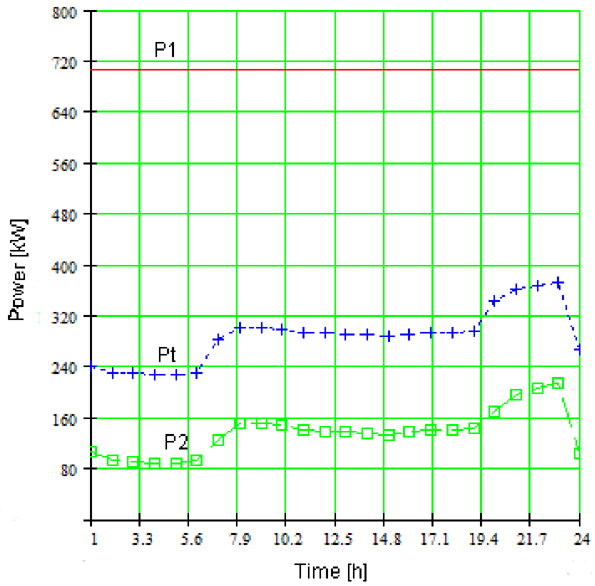

Fig. 9 Power consumption for different djustment methods

4. Economical aspects

The practice has shown that the investment cost of the auxiliary equipments for the maintenance of the safety of the variable rotation speed pumps represents about 10 % of the total exploiting costs. Thus, 90 % represents the energy consumption for the total exploiting period, which is approximately 15…20 years. At the same time, the obtained energy saving, using variable rotational speed pumps, will lead to a shorter recovery time of the investment costs.

In a power station operate dozens of pumps which power consumption is about 35% of its domestic consumption. Taking into account that domestic consume of a power station is about 10,000 kW, energy consumption of pumps 3,500 kW. Considering energy saved by using variable rotational speed compared with throttle control of 33%, for yearly operational time during winter 4,000 hours, could be saved 4,480,000 kWh. This could reduce the financial burden with about 500,000 dollars every year.

5. Conclusions

The water flow adjustment with variable rotation speed pumps is an advantageous optimization method of water pumping in urban heating stations, assuring the correlation between the heat demand and water discharge and obtaining, at the same time, important energy saving which can reach, under certain condition, even 60 %.

Using the rotation speed variation, the water pressure meet continuously to the required values, obtaining an important reduction of water losses in the system. At the same time, the high values of the pressure, which can lead to operation defects of the system equipments, are avoided.

Using frequency converters, the rotation speed of the power driven pumps can be increased, obtaining higher values than 50 Hz. Thus, the pumping capacity increases too. In this cases the lower capacity of a pumping station can increases, using frequency converters, replacing the engines with other with higher power.

For variation of the rotation speed the frequency converters represents the best solution, because these should be connected between the engine and the power source and set for the specific requirements. VFDs offer energy savings and a soft-starting capability. The voltage fluctuations that can occur in starting up large motors are also reduced. As reducing water flow by VFDs reduces head, pump and auxiliary wear and reduced. Motor shaft requirements decreases with cube of pump's rotational speed and this could life cycle costs of engine-pump assembly.

References

1. *K.Bienek, N.Groning,* „Die regelung die forderleistung von Kreiselpumper nuttels elektronischercher drehzahlverstellung“, Technische Berichte, nr. 6, 1987.
2. *R.Cyssau,* „Manuel de la regulation et de la gestion de l'énergie“, PYC, Paris, 1991.
3. *I. Georgescu* “Economii de energie prin acționarea cu turație variabilă a pompelor şi ventilatoarelor în automatizarea proceselor tehnologice”, Energetica, nr. 3, 1988. pp. 99-109.
4. *M. Ilina, S. Burchiu*, “Pompe cu turație variabilă în instalațiile de încălzire”, Rev. Instalatorul, nr. 2, 1996, pp. 5-9.
5. *I. Sârbu*, “Optimizarea energetică a sistemelor de distribuție a apei”, Ed. Academiei Române, Bucureşti, 1997.
6. *I. Sârbu, I. Borza*, “Energetic optimization of water pumping in distribution systems”, Periodica Polytechnica, Budapest, vol. 42, no. 2, 1998, pp. 141-152.
7. *I. Suceveanu*, “Analiza posibilităților de reglare a parametrilor tehnologici prin variația turației agregatelor”, Energetica, nr. 4, 1988, pp.156-160.
8. *G. McCormick, R.S. Powell*, “Optimal pump scheduling in water supply systems with maximum demand charges”, Journal of Water Resources Planning and Management, vol. 129, no. 3, 2003, pp. 372-379.