ENERGETIC OPTIMIZATION OF WATER PUMPING IN DISTRIBUTION SYSTEMS

Ioan SÂRBU and Ioan BORZA

The 'Politehnica' University of Timişoara
1900 Timişoara, Piata Victoriei, no. 2, Romania
Tel: 40 0 56-220371; Fax: 40 0 56-190321

Abstract

The paper presents some different solutions for the functional optimization of pumps in big water distribution systems. These solutions lead to the increasing of the power efficiency and a correlation of the pumped flow with the real consumption in the system, which result in an energy saving up to 30%, an important fact in the present energy conditions.

Keywords: distribution systems, water pumping, energetic optimization.

1. General Considerations

Pumped water distribution to users is an energy consuming process; it is considered that, in order to ensure a proper pumping pressure, 70...80% of the total consumed energy of the whole central energy supplying systems in industrially populated area is used only to this purpose. The energy consumption depends on the global efficiency of the distribution system, which is formed by the 2nd grade pumping stations and the distribution network; these systems work in close relation.

A great number of centralized water supplying systems in Romania fail to ensure the water supplying of users during certain hours of the day, due to a bad designing of the system or because the users have over-extended their consume, due to the bad functioning of the pumping stations or other causes.

On the other side, we must consider that for ensuring the optim supplying of users with water, the pumping stations would have to know the pressure values in the significant junctions of the distribution network.

The problem of optimizing the pumps' functioning for distribution networks implies problems related to the optimal dimensioning of the network and the correct choosing of the pumps, of main interest for each pumping station being the reduction of energy consumption to influence the economic efficiency of the pumping.

In this context, the aim of the present paper is the analysis of solutions for optimizing the functioning of pumps in large water distribution systems,

in order to increase the energetic efficiency of the pumps and to correlate the pumped water quantity with the real, existent, water consumption.

2. An Analysis of the Pumps Functioning in the Network, from the Energetic Perspective

As basic parameters the analysis has the specific energy used for pumping, and the specific energy of the system. The specific energy used for pumping w_p which represents the energy consumed for pumping a unit of volume; it is measured in kWh/m^3 and can be calculated using relation (1). The specific energy of the system w_s to represent the energy consumption for a given geodetic delivery head; it is measured in $kWh/(m^3 \cdot m)$ and can be calculated using relation (2):

$$w_p = 0.00272 \frac{H_p}{\eta}, \tag{1}$$

$$w_s = \frac{w_p}{H_g} = \frac{0.00272}{\eta \eta_r}, \tag{2}$$

where: H_p is the static head for the functioning point, in m; H_g – the geodetic delivery head, in m; η – the general efficiency of the pumping station; $\eta_r - H_g/H_p$ – the hydraulic efficiency of the distribution network.

The absorbed power P, in kW, for a certain rotation speed, can be calculated using relation:

$$P = \frac{\rho g Q H_p}{1000 \eta} = 3600 w_p Q, \tag{3}$$

where: ρ is the density of the water, in kg/m^3; g – gravitation acceleration, in m/s^2; Q-the pumped water flow, in m^3/s; w_p – the specific pumping energy, in kWh/m^3.

Generally, at centrifugal pumps made in Romania, the H_p/η ratio does not represent the maximal value for the efficiency η_{max} (*Fig. 1*), but rather a smaller value on the descending branch:

$$\eta \cdot w_{p\,min} \neq \frac{H_p}{\eta_{max}}. \tag{4}$$

If we consider an over-dimensioned pump (compared with the networks requirements) we have the situation presented in *Fig. 2*. Network's characteristic $H_{rl} = f(Q)$ places the starting point for the normal functioning of the pump in point F, which corresponds to the H_F load, the Q_F flow and the w_{pF} specific energy. For the minimal specific energy, w_{po} there is a correspondent point O.
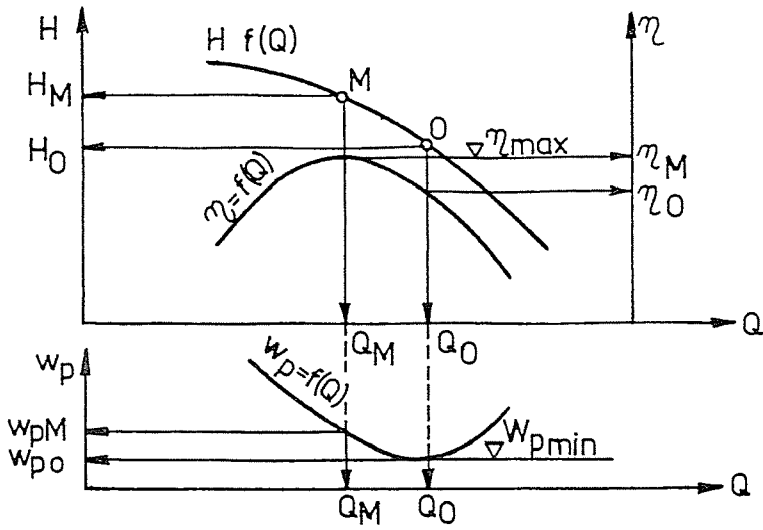
Fig. 1. Characteristic curves of a centrifugal pump
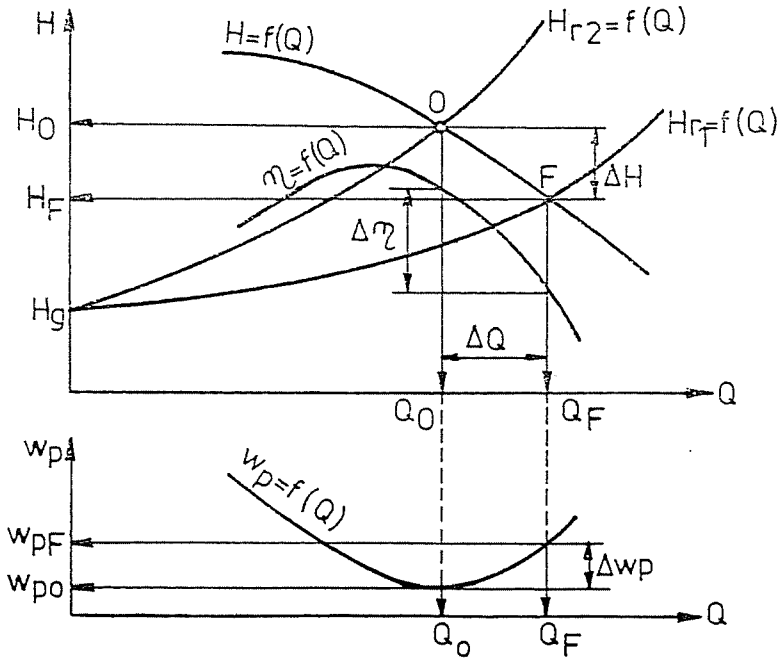

Fig. 2. Flow regulation using a valve

From relation (2) we can notice that the systems specific energy, w_s, is in reversed proportion to the total efficiency of the system:

$$\eta_t = \eta\eta_t \, , \tag{5}$$

and directly proportional to the specific pumping energy, w_p.

3. Solutions for Reducing the System's Energy Consumption

3.1. Increasing the Energetic Efficiency of the System

Considering the reduced number of standard types and the further development of the supplied area, the pumps to meet the functional requirements are usually over-dimensioned compared to the functioning conditions of the moment. Therefore, in some situations, the functioning point of the pumps sometimes migrates to the high flow area, even outside of the diagrams provided by the supplier.

In order to increase the efficiency of the system and to reduce the energy consumption, the functioning point should migrate towards point O (Fig. 2). For this, we can use a controlling system with a regulation valve.

By the partial shutting of the valve, network's characteristics turns into $H_{r2} = f(Q)$, and, according to the new functioning point, the flow reduces to Q_0, pump's head increases to H_0 and the specific pumping energy decreases to $w_{po} = w_{p\,min}$, the pump's efficiency increasing from η_F to η_0.

The increasing of the pumping head leads to a decreasing in the hydraulic efficiency of the network η_r which explains why in the literature [1,4,11,12] it is sustained that the valve controlled regulation system is not recommended, as it reduces the global efficiency of the system η_t.

By examining the specific energy's (w_p) curve we may notice that if the regulation is to be made on the pump's characteristic, placed under point O, corresponding to the minimal specific pumping energy, there is to be reached a decrease of the energy consumption and, accordingly, an increase in the global efficiency of the system (η_t) − η increases a lot more, even if η_r is reduced due to the partial shutting of the valve.

If the regulation of the functioning point is to be made above point O, by increasing the pumping head, the specific pumping energy increases accordingly, resulting in an increase of the energy consumption.

As a conclusion, from the point of view of the valve controlled regulation system, a functioning diagram of a centrifugal pump has two areas, delimited by the functioning point corresponding to the minimal pumping energy.

For heads over this point, the regulation is not to be made by valve control; regulation for lower heads (compared to this point) manages a reduction of the energy consumption.

Due to the existing variations in the water consumption in the distribution network, the pumping height H_p varies accordingly during pump's functioning, ranging around its pump's characteristic value.

Regulating using value control is to be made only during intervals in which the pump is functioning at heads $H_p < H_o$, ranging to $H_p = H_o$, and accordingly decreasing the flow from the nominal value Q_F to Q_o.

As any other regulation system, this method also requires a three elements system: the measuring device (transducer), the information processing device (regulator) and the functional element (electro-magnetic valve).

3.2. Correlating the Pumped Flow with the Real Water Consumption

The classical way of functioning for pumping stations of II grade is based on the hour-by-hour variation diagram of the water consumption, statistically determined [12]; its parameter's regulation is a step-by-step fashion, by connecting and disconnecting several parallel connected pumps.

Even if the water flow control by using the pump's valve leads to an increase in the distribution system's energetic efficiency in cases with nominal pumping heads lower to the optimal pumping head (corresponding to a minimal specific energy), this optimizing method induces a high rate of wearing out of the shuttering devices; also, the pumps are forced to function in less usual regimes.

The most advantageous method to realize a variation in the water flow is by modifying the rotation speed of the pump's electric machine, transforming it into a regulation element and so eliminating the use of the shut-off valve.

Water flow regulation (*Fig. 3*) is no longer done by modifying the network's characteristic and by moving the functioning point F_1 on the pump's constant characteristic (as in the regulation method using a shut-off valve), but rather by moving the functioning point in F_2 due to the modification of pump's characteristic H (at various rotation speeds n_1, n_2) on the network's constant characteristic H_r. The functioning point F_2 corresponds to the pumping head H_{F2} reduced with the pressure drop on the eliminated valve.

Pump's characteristic at reduced rotation speed can be calculated and represented using the similitude relations:

$$\frac{Q_1}{Q_2} = \frac{n_1}{n_2}, \tag{6}$$

$$\frac{H_1}{H_2} = \left(\frac{n_1}{n_2}\right)^2. \tag{7}$$

The variation of water flow, according to relation (6) is directly proportional to the pump's electric machine variation of the rotation speed, which is con-
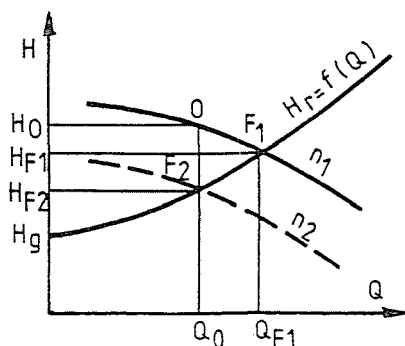
Fig. 3. Flow regulation using rotation speed variation

trolled directly by the regulation device of the automatic regulation system. This relation is represented in formula (8), wherefore the efficiency (η_2) in point F_2, for rotation speed n_2, depending on efficiency η_1 for rotation speed n_1 can be deduced:

$$\eta_2 = 1 - (1 - \eta_1) \left(\frac{n_1}{n_2} \right)^{0.1} . \tag{8}$$

In fact, for most pumps, and especially for the big ones, the modifications interfered in the efficiency of the system can be neglected for a rotation speed variation ranging at 1/3 from the nominal rotation speed.

In *Fig. 4* the variations of H, Q, P, η characteristics corresponding to the variation of rotation speed n, for centrifugal pumps have been represented; it can be noticed that by reducing with 20% the rotation speed, the absorbed power reduces by 50% and the pump's efficiency remains practically unmodified. As a conclusion, by regulating the pumps' rotation speed it is possible to reduce the amount of pumping energy.

In order to correlate the pumped flow with the real water consumption requirements and to ensure the necessary pressure using minimum energy, an automatic system (*Fig. 5*) has been designed composed by: an asynchronous electric machine with a breakdown rotor associated with a static frequency converter (with tiristor). The system has a simple structure, can easily be repaired and cleaned, and at a comparatively low price.

The command given by the pressure controller is taken by the rotation speed converter (which is to be surveyed by a processing computer).

Electric pressure traducers 1 dispatch the pressure from the significant distribution junctions by connecting lines 2 using electric signals of 2...10 ma c.c. or 4...20 ma c.c., to the regulation milliampermeters 3 placed in the industrial pumping stations. Meanwhile, the electric signals are concomitantly transmitted also to an electric recorder 4, in serial connection with the regulation milliampermeters, in order to ensure the continuous recording on a pressure diagram from (at most) 12 measuring points. Signalling boards
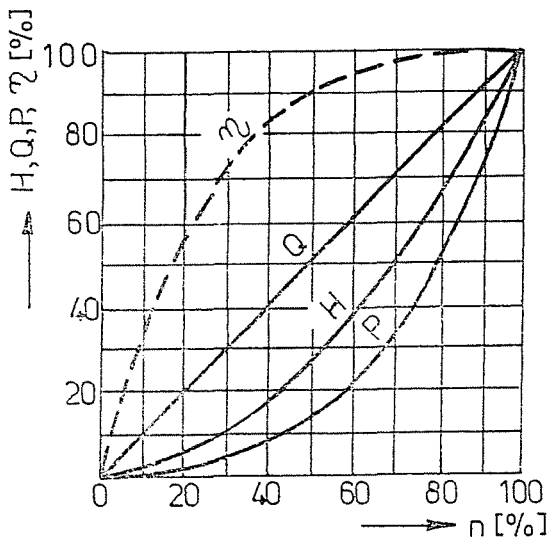
Fig. 4. Centrifugal pumps' characteristics variation according to the rotation speed variation

5 have signalling lamps and bells controlled by the regulation milliamper-meters through minimum and maximum relies. The milliampermeters also control (by a continuous-discontinuous programmer 6) by connection lines 7, the connection or disconnection of pumps 10 electric machines 9 to the energy supply network 8. The continuous-discontinuous programmer is connected through lines 11 with a processing computer 12 which makes an initial calculus of the minimal and maximal values of the required pressures in the network's main points, in order to ensure an optimal water supply at a low energy cost. Electric machines with variable rotation speed are connected with rotation speed traducers 13, which send their signal to the comparison-making element 14 – this element takes into consideration the signal's value and controls the static frequency converter 15 accordingly, the converter works with one or more pumps' electric machines.

The rotation speed converter enables a primary regulation by connecting or disconnecting the pumps and a secondary regulation in the connecting intervals by modifying the rotation speed of the pumps' electric machines.

If several pumps are to work in parallel connection, the variation of rotation speed can be made for a single pump (while the other one works at nominal rotation speed), the rotation speed converter automatically connecting itself to any of the pumps. So, it is necessary to equip the pumping station with $n_p = n_c + n_v$ number of pumps, where n_c is the number of classical pumps (P_c) and n_v the number of variable rotation speed pumps (P_v).
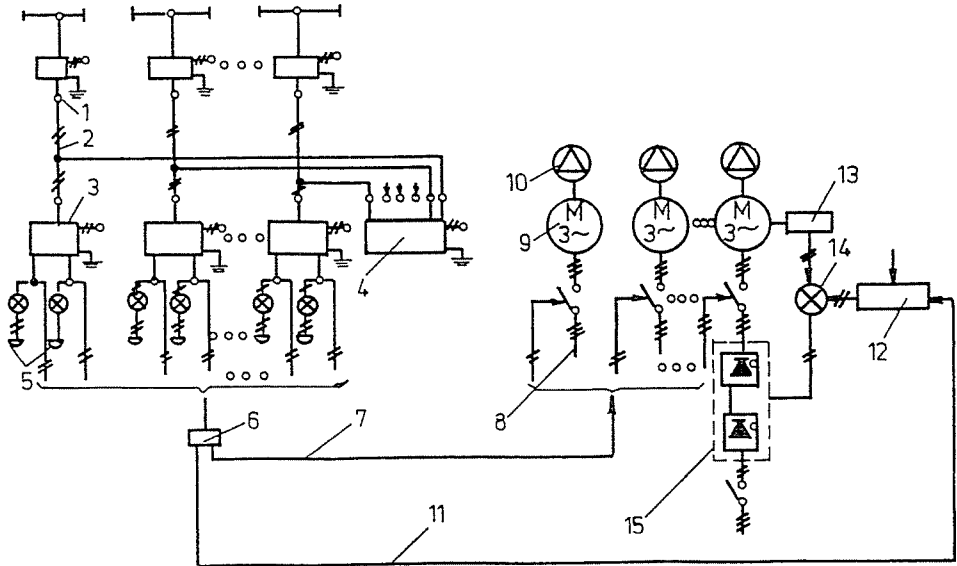
Fig. 5. Scheme of water distribution pumps' functioning optimization system using rotation speed's regulation (1 – pressure transducer FE 1 GM; 2,7,11 – connecting lines; 3 – regulation milliampermeter 1 ARE 192; 4 – electric recording system ELR 362 A; 5 – signalling board; 6 – continuous-discontinuous programmer ELX 733; 8 – electric network; 9 – electric machine; 10 – pump; 12 – processing computer; 13 – rotation speed transducer DT 171; 14 – comparison-making element; 15 – static frequency converter CSFV)

This solution has the following advantages:

- a large range of rotation speed's variations can be achieved;
- a certain constant rotation speed can be maintained;
- can easily be integrated in an automatic controlling system;
- is easily integrated into an existing pumping system.

Choosing of the optimal flow regulation method is made according to the obtained energy save and the depreciation period of the supplemental investments in the adopted regulation system.

To calculate the energy save to be obtained by the use of a certain regulation method, functioning conditions are to be taken into consideration:

- the distribution network's characteristic;
- the water consumption's characteristic, which represents the variation of the required flow for a day.

The specific energy consumption, w_e, in % for an optimal exploitation period T_p of the pumps can be calculated using relation:

$$w_e = \frac{\int_0^{T_p} Pdt}{\sum_{i=1}^{24} \frac{Q_i H_i}{\eta_i} T_p} \cdot 100\,, \tag{9}$$

where: Q_i, H_i, η_i are pumps' characteristics in classical functioning at i hour of a day; $\int_0^{T_p} Pdt$ – represents the energy consumption during interval T_p at flows different from Q_i.

For analyzing the pumping in water supplying systems to determine the functioning points for pumps working in different regimes, we can also use the numeric calculus model [10] for pumps with constant and variable rotation speeds.

4. Comparative Energetic Analysis of Pumping Station's Functioning with Classical and Optimized Regulation Systems

The energetic and economic efficiency of above presented optimizing methods can be shown by a comparative analysis of a pumping station's functioning working with 6 pumps of 12 NDS-1450 type in the water distribution system of a big industrial center in Romania, which has to ensure the daily supplying of 172.800 m^3 of water.

The obtained numeric results based on the characteristic curves in *Fig. 6* are presented in *Table 1*. This table comparatively shows the specific energy w_e and the energy savings realized during a 360 days functioning period (T_p) by the use of valve regulation system and that of rotation speed variation, related to the real characteristic of the water consumption, compared with the classical functioning of the pumps (which relies on the statistic variation of the water consumption).

By this analysis it can be noticed that the optimized functioning of the station using the rotation speed regulation system leads to a specific energy consumption of 80% compared to the 88% when using valve regulation. Compared to the classical functioning, the rotation speed regulation system ensures the saving of 2280 MWh/year, and the valve regulation 1345 mWh/year.

As a conclusion, the rotation speedb regulation ensures a supplementary energy saving of approximately 10% compared to the valve regulation one.

Table 1. The specific energy consumption and energy savings obtained by the use of optimization methods

Regulation method	Hours period	No. of pumps function-ing	Pumped flow Q [m³/s]	Pumping height H_p [m]	Absorbed power P [kW]	Consumed energy W_e [kWh/day]	Specific energy consump-tion w_e [%]
0	1	2	3	4	5	6	7
Classical	0–4	$3P_c$	1.47	38.6	696.3	31705.6	100
(start-stop)	4–10	$6P_c$	2.48	49.8	1730.8		
	10–14	$4P_c$	1.91	42.5	995.4		
	14–17	$5P_c$	2.18	45.7	1303.1		
	17–22	$6P_c$	2.48	49.8	1730.8		
	22–24	$4P_c$	1.91	42.5	995.4		
Optimized	0–5	$3P_c$	1.42	38.6	672.6	27970.5	88
(valve	5–6	$6P_c$	2.25	53.0	1424.0		
control)	6–7	$6P_c$	2.48	49.8	1730.8		
	7–8	$6P_c$	2.25	53.0	1424.0		
	8–10	$5P_c$	2.08	47.5	1138.2		
	10–12	$4P_c$	1.91	42.5	995.4		
	12–13	$5P_c$	1.81	56.0	1181.6		
	13–15	$4P_c$	1.91	42.5	995.4		
	15–16	$6P_c$	2.08	47.5	1138.2		
	16–20	$6P_c$	2.25	53.0	1424.0		
	20–23	$6P_c$	2.46	50.0	1544.1		
	23–24	$4P_c$	1.81	43.0	1122.6		
Optimized	0–5	$2P_c + 1P_v$	1.42	37.6	655.2	25375.5	80
(water	5–6	$5P_c + 1P_v$	2.25	45.5	1222.5		
flow	6–7	$6P_v$	2.48	49.8	1730.8		
control)	7–8	$5P_c + 1P_v$	2.25	45.5	1222.5		
	8–10	$5P_c$	2.08	43.0	1030.3		
	10–12	$4P_c$	1.91	42.5	995.4		
	12–13	$5P_c + 1P_v$	1.81	40.0	708.9		
	13–15	$4P_c$	1.91	42.5	995.4		
	15–16	$5P_c + 1P_v$	2.08	43.0	1030.3		
	16–20	$5P_c + 1P_v$	2.25	45.5	1222.5		
	20–23	$5P_c + 1P_v$	2.46	49.6	1534.5		
	23–24	$3P_c + 1P_v$	1.81	40.0	708.9		
Energy savings $\Delta W_{e,2-1}$	[MWh/year] [%]		1345.0 11.6				
Energy savings $\Delta W_{e,3-1}$	[MWh/year] [%]		2280.0 20.0				
Energy savings $\Delta W_{e,3-2}$	[MWh/year] [%]		935.0 8.4				

5. Conclusions

From energetic point of view, water distribution pumps' regulation through valve regulation is recommended for use only in the diagrams area where the pumps characteristics are placed above the optimal point corresponding to the minimal specific pumping energy.
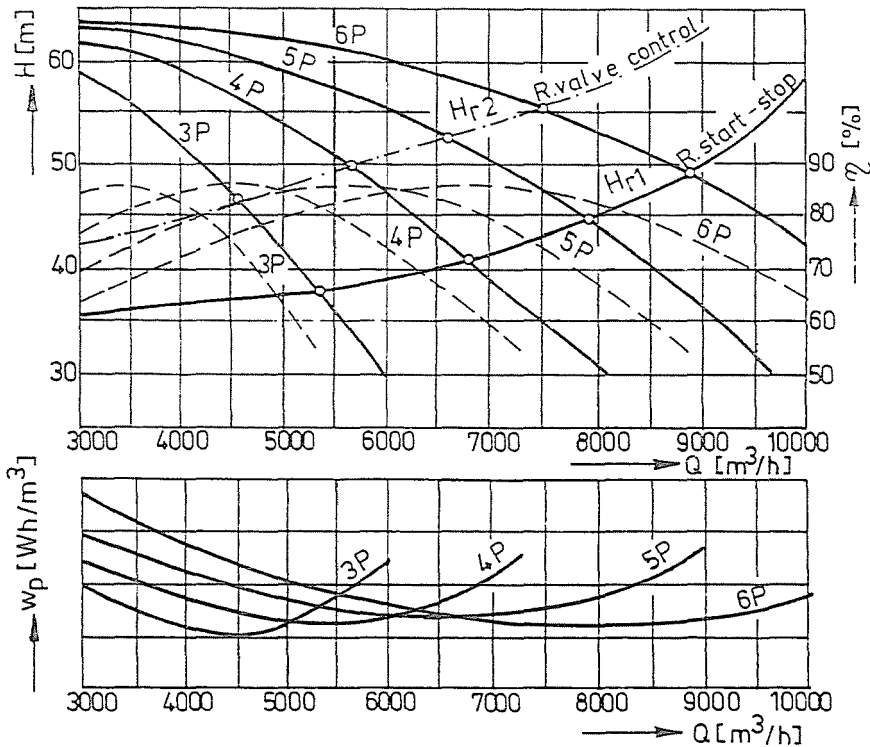

Fig. 6. $H - Q$, $\eta - Q$, $w_p - Q$ characteristic curves and functioning points for various parallel connection pumps' design of 12 NDS–1450 type

For existing pumping stations, which fall in the above mentioned categories, valve regulation is a simple and efficient energetic optimization system. Therefore, pumps' manufacturers should mention in their instructions the specific energy curves for 1 pumped m³.

Energetically speaking, regulation through modifying the rotation speed is the most advantageous method for the functional optimization of pumps, as it correlates the pumped water flow with the real water consumption, and ensures important energy savings (in certain conditions, ranging towards 30%). In order to ensure the general spreading of this regulation system in large distribution systems, pumps' guidelines should contain clear

indications regarding pumps' possibilities for functioning under variable rotation speeds.

Notations

H_p –   static head for functioning point;
H_g –   geodetic delivery head;
η –   general efficiency of the pumping station;
η_r –   hydraulic efficiency of the distribution networks;
ρ –   density of the water;
g –   gravitation acceleration;
Q –   pumped water flow;
w_p –   specific pumping energy;
n –   rotation speed;
P –   absorbed power;
W_e –   consumed energy;
T_p –   exploitation period of the pumps;
w_e –   specific energy consumption;
P_c –   classical pump;
P_v –   variable rotation speed pump.

References

[1] ANTON, I. – POPOVICIU, M. – FITERO, M.: Hidraulică şi maşini hidraulice, Ed. Diadactică şi Pedagogică, Bucureşti, 1978.
[2] BAIU, S.: A Practical System for Applying VSDs to Pumping Systems, *Electricity Today*, No. 2, 1992.
[3] BIENEK, K. – GRONING, N.: Die Regelung der Forderleistung von Kreiselpumpen nuttels elektronischer Drehzahlverstellung, *Tehnische Berichte*, No. 6, 1987.
[4] GEORGESCU, I.: Economii de energie prin acţionarea cu turaţie variablă a pompelor şi ventilatoarele în automatizarea procelor tehnologice, *Energetica*, No. 3, 1988.
[5] IONEL, I.: Instalaţii de pompare reglabile, Ed. Tehnică, Bucureşti, 1976.
[6] LYNCH, T.: Variable-Speed Drives for Pumping, *World Pumps*, No. 5, 1987.
[7] PAPADACHE, I.: Automatizări industriale, Ed. Tehnică, Bucureşti, 1978.
[8] SÂRBU, I.: Optimizarea funcţională a pompelor în sistemele de distribuţie a apei, *Hidrotehnica*, No. 8, 1993.
[9] SÂRBU, I.: Energetical Optimization of Water Distribution Systems, Ed. Academiei Române, Bucureşti, 1997.
[10] SÂRBU, I.: Calculul instalaţiilor pentru construcţii – Metode numerice şi de optimizare, Ed. Tehnică, Bucureşti, 1994.
[11] SUCEVEANU, I.: Analiza posibilităţilor de reglare a parametrilor tehnologici prin variaţia turaţiei agregatelor, *Energetica*, No. 4, 1988.
[12] TROFIN, P.: Alimentări cu apă, Ed. Didactică şi Pedagogică, Bucureşti, 1983.
[13] Catalog de pompe, Uzina Aversa, Bucureşti, 1975.
[14] Les économies d'energie électrique dans les systèmes de pompage, *Hydro-Quebec*, 1993.