Scientific Bulletin of the
Politehnica University of Timisoara
Transactions on Mechanics Special issue

The 6th International Conference on
Hydraulic Machinery and Hydrodynamics
Timisoara, Romania, October 21 - 22, 2004

MODELLING OF THE AUTOMATIC ADJUSTMENT OF THE OPTIMUM OPERATING POINT OF A PUMP DEPENDING ON THE REQUIREMENTS OF THE WATER SUPPLY

Teodor MILOŞ, Associate Professor *
Department of Hydraulic Machinery
"Politehnica" University of Timisoara

Alexandru BAYA, Professor
Department of Hydraulic Machinery
"Politehnica" University of Timisoara

Liviu Eugen ANTON, Professor
Department of Hydraulic Machinery
"Politehnica" University of Timisoara

Adrian STUPARU, PhD Student
Department of Hydraulic Machinery
"Politehnica" University of Timisoara

**Corresponding author*: Bv Mihai Viteazu 24, 300223, Timisoara, Romania
Tel.: (+40) 256 403683, Fax: (+40) 256 403682, Email: milost@home.ro or mh@mec.utt.ro

ABSTRACT

For many pumping systems appears the problem of the automatic adjustment of the operating point correlated with the requirements of the water supply. In the conditions of our days equipments the adjustment of the operating point can be done so that the pump efficiency to be maximum and the energy consumption to be minimum.

The results presented in the paper were obtained from a test facility at the Hydraulic Machinery Laboratory that contains a pump with variable rotational speed, a real time computerized data acquisition system for all the measured parameters and professional software for adjusting the rotational speed of the pump depending on the requirements imposed by the consumers. The pump efficiency is monitored in real time using the thermodynamic method, with the P22 measuring equipment. The efficiency is determined using the temperatures measured upstream and downstream the pump, as well as the measured upstream/downstream static pressure increase. The professional software commands the adjustment of the rotational speed so that the operating point is optimum with respect to the energetic consumption and the pressure value to the consumers to be maintained in the initial recommended limits.

KEYWORDS

pumping station, operating point, variable speed approach, efficiency, energy saving, thermodynamic method

NOMENCLATURE

Q [m^3/s] flow rate
$\eta_{i\,pump}$ [%] pump efficiency
$P_{deliver}$ [kW] power delivered
P_{loss} [kW] power loss
P_S [kW] shaft power
P_{abs} [kW] electrical consumed power
H_g [m] geodesic pumping head
C_d [m] losses constant
Δh_t [-] the increase in total enthalpy
p [Pa] pumping pressure
v [m/s] velocity
ρ [kg /m^3] density
g [m/s^2] gravity
H_{ec} [m] pipe network operation characteristic
H [m] pumping head
η_{em} [%] electrical motor efficiency
N_{dy} [-] number of days in an year
N_{hd} [-] number of hours in a day

Subscripts and Superscripts

O *outlet*
I *inlet*

1. INTRODUCTION

The Hydraulic Machinery Laboratory of "POLITEHNICA" University of Timisoara has a real time computerized data acquisition system which uses the program LabView 5.1 and the portable equipment P22 for the measurement of the energetic parameters of a centrifugal pump, based on the thermodynamic method. In order to set a general testing method, which can be applied in any pumping system, a case study was released on a hydraulic loop from a test facility at the Hydraulic Machinery Laboratory.

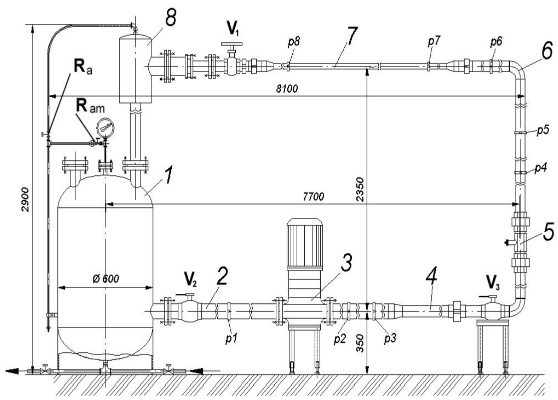

Figure 1. Multifunctional installation loop facility (without the measuring instruments)

2. EXPERIMENTAL INSTALLATION AND MEASURING INSTRUMENTS

The installation contains the following parts:

1 - A suction buffer water tank with a capacity of 200 l which represents a reserve of liquid.

2, 4 - Four pipes, with a nominal diameter D=65 mm, for the connection of the pump with the hydraulic loop.

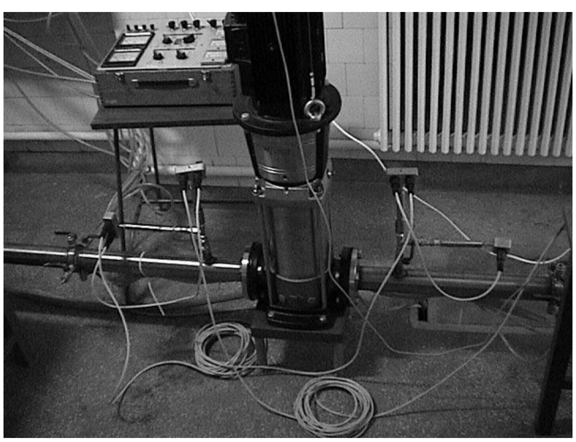

Figure 2. Connection of the pressure and temperature probes for the pump testing

For the equipement that uses the thermodynamic method are necessary tapping points to measure the differential temperature and pressure across the pump, fitted with a ½ inch ball valve (or equivalent on either side of the pump, about 2 pipe diameters away from the pump flanges. The temperature probes are inserted into the flow, and the pressure sensors are mounted on a T-piece, fitted to the gate valve.

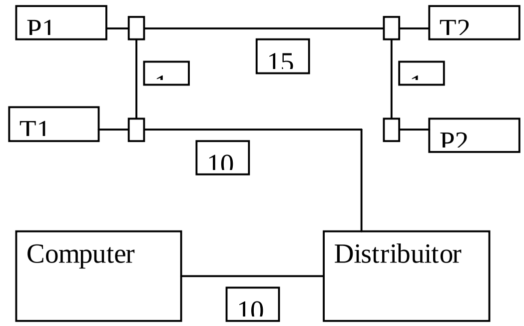

Figure3. Assembling of the P22 equipment

3 - The centrifugal pump is a multistage in line pump, type CRNE 32-4 produced by Grundfos. The electrical equipment of the pump contains a frequency converter which permits the control of the rotational speed of the pump in 20 steps between 500 and 2900 rot/min. At the same time an adjusted speed is automatic maintained independent of the charge given by the adjustments from the hydraulic loop.

5 - A flow meter with a special transducer based on Hall effect has been used.

6, 7, 8 - Sections for the experimental determination of the local and distributed hydraulic losses.

The measurements of the energetic characteristics of the pump are performed using the thermodynamic method and for verifying these results the parameters of the classical method are measured: pressures, flow rates, electrical consumed power and rotational speed. The used probes are connected to a real time computerized data acquisition system.

The program used for data acquisition is LabView 5.1. LabView contains application libraries for data acquisition, for data analysis and for data visualisation. LabView also includes tools for developing the applications so that data flux through the application can be visualised and the application can be ran step by step for a better debugging.

3. THE SIMULATION OF THE EXPLOITATION OF A CENTRIFUGAL PUMP IN A LABORATORY

3.1. The energetic characteristics of the tested pump

In a first phase there were tested the energetic parameters *Q*, *H*, P_S measured and calculated with the classical method and then these parameters were compared with those obtained with the thermodynamic method. It results a good overlapping of the results. The differences were in the range of errors. Then these parameters were compared with the reference data given by the pump producer. The tests were made at 3 different rotational speeds so that the pump operation characteristic can be obtained. The rotational speeds were: n_1=2900 rot/min as a maximum reference speed (100%), n_2=2320 rot/min (80%) and n_3=1740 rot/min (60%).

$$\eta_{i,pump} = \frac{P_{deliver}}{P_{deliver} + P_{loss}} = \frac{\Delta h_{t,deliver}}{\Delta h_{t,deliver} + \Delta h_{t,loss}} = \frac{\frac{1}{\rho}\cdot(p_O - p_I) + \frac{1}{2}\cdot(v_O^2 - v_I^2) + g\cdot(z_O - z_I)}{\frac{1}{\rho}\cdot(p_O - p_I) + \frac{1}{2}\cdot(v_O^2 - v_I^2) + g\cdot(z_O - z_I) + \Delta h_{t,loss}} \quad (1)$$

$$\eta_{Pump} = \frac{Q\cdot\left[(p_O - p_I) + \frac{\rho}{2}\cdot(v_O^2 - v_I^2) + \rho\cdot g\cdot(z_O - z_I)\right]}{P_S} \Leftrightarrow Q = \eta_{Pump}\cdot\frac{P_S}{(p_O - p_I) + \frac{\rho}{2}\cdot(v_O^2 - v_I^2) + \rho\cdot g\cdot(z_O - z_I)} \quad (2)$$

In figure 4 and 5 is shown pumping head vs. flow rate and pump efficiency vs. flow rate. These results were obtained with the thermodynamic method and were compared with the reference data.

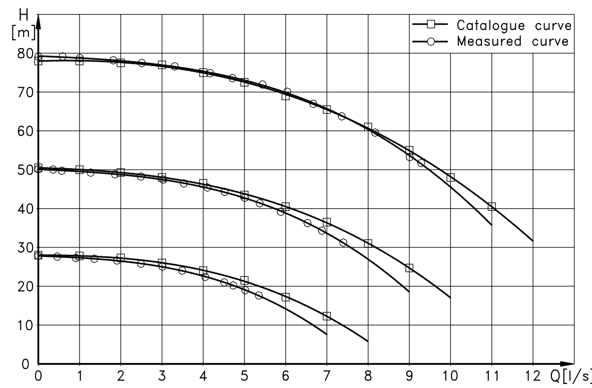

Figure 4. Pumping head vs. flow rate, measured and given by the pump producer

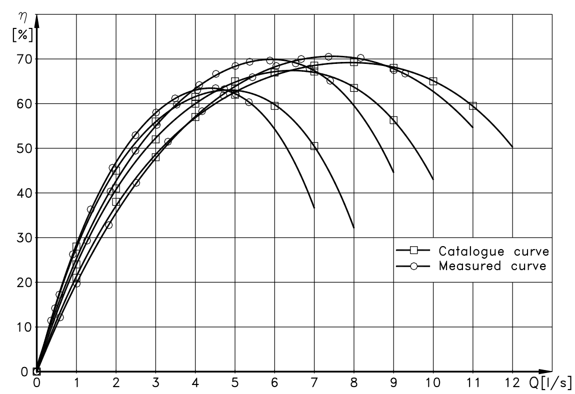

Figure 5. Pump efficiency vs. flow rate, measured and given by the pump producer

Our experimental results obtained with the thermodynamic method are in a good agreement with reference data. Larger deviation it is observed at maximum flow rates where it seems that the tested pump is a bit different than the prototype for which the data are given by the pump producer.

With these two curves we can build the pump operation characteristic which gives us information about the optimum operating point of the pump. The identification of the equal efficiency curves was made analytical, using a program developed by us and the graphic postprocessor program used was developed in AutoCAD under AutoLisp.

The results obtained for the pump operation characteristic are shown in figure 6.

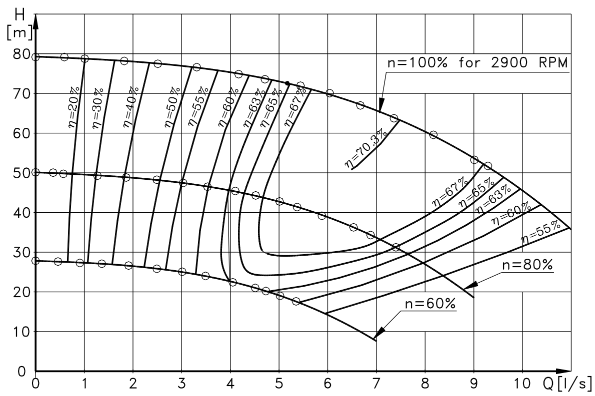

Figure 6. The pump operation characteristic according to measured data with the thermodynamic method

3.2. The energetic characteristic of the pipe network

The pipe network operation characteristic, H_{ec}, represents the amount of the losses from the hydraulic loop exterior to the pump and it is calculated with the formula:

$$H_{ec}=H_g+C_d\cdot Q^2 \qquad (3)$$

The losses constant is calculated for an operating point measured from the pump characteristic knowing that $H_{ec}=H$ and from equation (3) results:

$$C_d = \frac{H - H_g}{Q^2} \qquad (4)$$

For the installation from the laboratory, being a hydraulic circuit, $H_g=0$. The other points of the pipe network operation characteristic are calculated giving values to flow rate from zero to the measured flow rate.

Having an installation with variable rotational speed, the pipe network operation characteristic was obtained adjusting the flow rate through the modification of the rotational speed. The results are presented in figure 7.

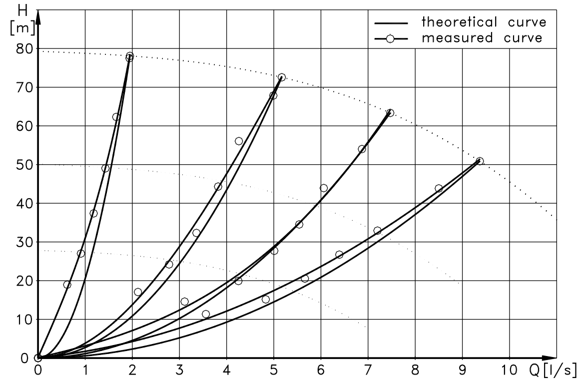

Figure 7. The pipe network operation characteristic measured and calculated

3.3. A case study on energy saving from the optimum combination of the adjusting flow rate through rotational speed and of adjusting flow rate through the outlet vane

The pumping station behaviour results by overlapping the pump operation characteristic at variable rotating speed on the pipe network operation characteristic. A minimum flow rate Q_{min}, a medium flow rate Q_{med} and a maximum flow rate Q_{max} can be estimated by tacking into account the requirements of the consumers from a network supplied by the pumping station. The share of these flow rates in the exploitation is expressed in percents through a coefficient, C_p, which results from a statistical study.

Also, for the closed hydraulic loop from the laboratory we assume that it has to insure a constant pressure in conformation with a constant pumping head, H_{ct}=50 m, for the following domains of flow rate:

ΔQ_{min}=4÷5 l/s with a coefficient of C_{pmin}=20 %
ΔQ_{med}=5÷8 l/s with a coefficient of C_{pme}=65 %
ΔQ_{max}=8÷9 l/s with a coefficient of C_{pmax}=15 %

The corresponding flow rates for the three domains are: Q_1=4 l/s; Q_2=5 l/s; Q_3=8 l/s; Q_4=9 l/s. To these flow rates are corresponding the pumping heads H_1, H_2, H_3, H_4 according to the pumping head characteristic for the maximum rotational speed.

If the pumping station would not have the possibility to adjust the rotational speed than the flow rate adjustment on the consumers would be realised only through the outlet vane and on the given domain will be provided a covering pumping head between 75 m and 53 m, although in the pipe network would be sufficient a 50 m pumping head. Even if the pump efficiency is relatively good on this domain it can be proved that a big part of the consumed energy is unnecessarily wasted.

If it is take into consideration the possibility of adjusting the rotational speed than it becomes possible the adjusting of the installation so that the pumping head to be constant, H_c=50 m, and provides to any consumer from the network optimum operating conditions. On the industrial installation the adjusting through outlet vane is realised on the consumer and the adjustment through rotational speed is performed in the pumping station, maintaining all the time a constant pumping head on the outlet of the pumping station.

The operating of the pump on the three domains of flow rate it observes that the efficiencies and the pumping heads are sensible different from an operating point to another. That is why in the following section it is presented an averaging method of the power on the three exploitation domains.

The shaft-power is calculated with the formula:

$$P_S = \frac{P_u}{\eta_{pump}} = \frac{\rho g Q H}{\eta_{pump}} \qquad (5)$$

Important is the electrical power consumed in the power station and which is affected by the efficiency of the electrical motor η_{em} = 85 %.

Two efficiency curves are used for the calculus. The first one corresponds to the operating pump at maximum rotational speed $\eta_{100\%} = f(Q)$ and the second one $\eta_{50} = f(Q)$ results from the characteristic curve for $H = H_{ct}$ = 50 m.

For a good averaging of the powers on the considered domains it is computed the electrical consumed power in 25 points for each interval of 1 l/s. The medium power will be the average of the powers on each considered domain.

The equation used is:

$$\Delta P_{abs} = \frac{\rho \cdot g \cdot Q}{\eta_{em}} \cdot \left(\frac{H_{100\%}}{\eta_{100\%}} - \frac{H_{50}}{\eta_{50}} \right) \qquad (6)$$

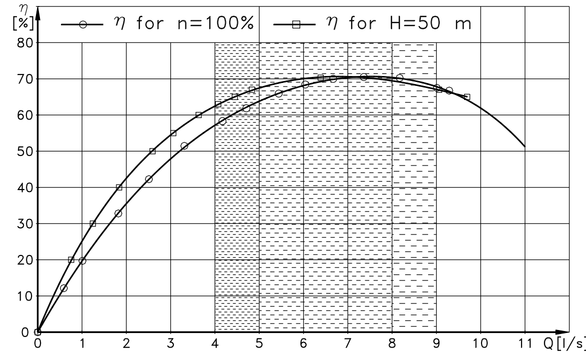

Figure 8. Efficiency curves for the two situations

The averaging of the power on the three domains it is realised with the equation:

$$\left(\Delta P_{abs}\right)_{med} = \frac{\sum_{k=0}^{N} \Delta P_{abs_k}}{N+1} \qquad (7)$$

The saving of consumed energy depends on the working time according to the equation:

$$\Delta E = \left(\Delta P_{abs}\right)_{med} \cdot N_{dy} \cdot N_{hd} \cdot C_p \text{ [kWh]} \qquad (8)$$

The results obtained for the three domains are presented in table 1.

Table 1

Flow rate domains	C_p [%]	$P_{abs100\%}$ [kW]	P_{abs50} [kW]	$(\Delta P_{abs})_{med}$ [kW]	ΔE [kWh]
$Q_1 \div Q_2$	20	6.344	3.980	2.364	4.142
$Q_2 \div Q_3$	65	7.308	5.367	1.941	11.052
$Q_3 \div Q_4$	15	8.076	7.181	0.894	1.175

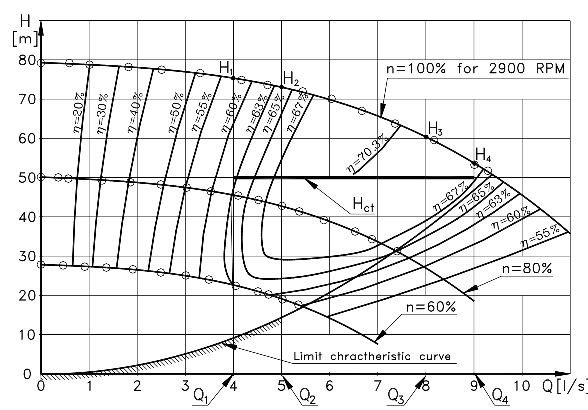

Figure 9. The characteristic curves of the pump

In figure 10 is presented the shape of the hydraulic characteristics at the limit of the domains defined above. Also here it remarks the rotational speed domains where the pump or the pipe network is adjusted (through the outlet vane in the laboratory or through the network consumers of the industrial installation) in order to obtain constantly a pumping head of H = 50 m.

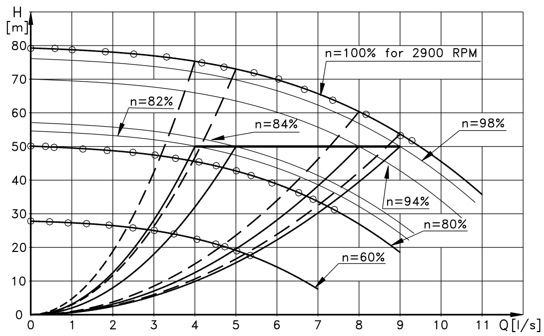

Fig. 10 The exploitation domains and the limit hydraulic characteristics

4. CONCLUSIONS

- The modeling of the automatic adjustment of a pump operating in a pumping station so that the pumping head to remain constant indifferent of the operating flow rate trot out first the economic advantage through the energy saving realized in time.
- The hydraulic network is not overcharged anymore at extreme pressures, which could lead to damages in case of uncontrolled manoeuvres.
- Using the thermodynamic method for the measuring of the parameters of the pump it allows in time the monitoring of the exploitation of a pumping station and than the prescription of an optimum adjusting mode for the entire flow rates domain imposed by the consumers.
- The averaging of the economic efficiency on the three operating domains allows a much precise appreciation than the estimation at the medium flow rate of each domain.

REFERENCES

1. Gandhi B.K., Singh S.N., Seshadri V., 2001, *Performance Characteristic of Centrifugal Slurry Pumps*, Journal of Fluid Engineering
2. Anton L.E., Baya A., Milos T., Resiga R., 2002, *Experimental Fluid Mechanics,* Vol. 1, Ed. Orizonturi universitare, Timisoara
3. Kudo K., 1994, Japanese experience with a converter-fed variable speed pumped-storage system, Hydropower & Dams
4. Meschkat S., Stoffel B., Irmscher R., Prien K.-J., Ilg F., Mollenkopf G., 2000, Applicability and limitations of the thermodynamic determination of efficiency in the frame of condition orientated maintenance of centrifugal pumps in drinking water plants, Pump Users International Forum, Karlsruhe
5. ***, 2001, LabView 5.1 User's Guide
6. ***, 2002, P22 Pump Monitor Instruction Manual