Thermodynamic method for pumps efficiency monitoring and flow rate estimation, and application to a multistage pump

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Abstract: The thermodynamic method is used for experimental determination on pumps and turbines being recommended by the IEC 60041. This paper presents a modern installation for the determination of the functioning characteristics and performances of the turbo pumps using the thermodynamic method. The system is conducted by a computer and the experiment is tacking place with real time data acquisition and processing. The application refers to the testing of a multistage in line pump, type CRNE 32-4 produced by Grundfos. After the comparison of the experimental results with those given by the producer of the pump the conclusions regarding the efficiency, the accuracy and the technical and economical benefits of the thermodynamic method are presented.

Keywords pump efficiency, flow rate estimation, thermodynamic method .

Nomenclature

Q [m^3/s] – flow rate of the pump
η_p [-] – pump efficiency
η_e [-] – motor efficiency
E_m [J/kg] – mechanical energy per unit mass of fluid
E_h [J/kg] – hydraulic energy per unit mass of fluid
δE_m [J/kg] – correction factor due to imperfect measuring conditions and secondary phenomenon
P_W [kW] – electrical input power to the motor of the pump
p [Pa] – pumping pressure
T [K] – water temperature in measuring sections
A [m^2] – cross-sectional area
z [m] – elevation of the measuring section regarding a reference plane
ρ [kg /m^3] – density of water
g [m/s^2] – acceleration due to gravity
$\overline{a}$ [m^3/kg] – isothermal coefficient of the water
c_p [J/(kg·K)] – specific heat of the water

Subscripts

1 – inlet
2 – outlet

Introduction

Economical and social development of the cities leads to capital changes in the daily and annual water consumption. The water supply is assured by one or more pumping stations. The adaptation of the operating parameters of the pumping stations to the dynamic of the consumption and the most efficient exploitation is a serious challenge for the decision factors from local administration.

The Hydraulic Machinery Laboratory of "POLITEHNICA" University of Timisoara has a 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 to any pumping system, a case study was released on a closed hydraulic loop from a test facility at the Hydraulic Machinery Laboratory. This hydraulic loop is fully equipped with modern measuring instruments for the testing of the pump and for fluid mechanics experiments.

The principle of the thermodynamic method

The thermodynamic method results from the application of the principle of energy conservation (first law of the thermodynamic) to the energy transfer between the water and the rotor. The specific mechanical energy of the rotor it can be determined by measuring the functioning variables (pressure, temperature, velocity and vertical height from a reference plane) and from the thermodynamic properties of the water. The necessity of measuring the flow rate so that the efficiency could be obtained is eliminated by using specific mechanical energy and specific hydraulic energy.

The applicability of this method was limited because of the lack of uniformity of the measured values in the reference section of the machine, the limitation of the measuring equipment and the relatively high number of corrective terms due to imperfect measuring conditions and could be used only for specific hydraulic energies larger than 1000 J·kg^{-1} (heads bigger than 100 m). Due to new measuring equipments like the one used by us the applicability of the method could be extended to pumps with smaller pumping heads.

The hydraulic efficiency of a pump is defined by IEC 60041 like this:

$$\eta_p = \frac{E_h}{E_m} \quad (1)$$

The specific mechanical energy is given by the equation:

$$E_m = \overline{a} \cdot (p_2 - p_1) + \overline{c}_p \cdot (T_2 - T_1) + \frac{\left(\frac{Q}{A_2}\right)^2 - \left(\frac{Q}{A_1}\right)^2}{2} + g \cdot (z_2 - z_1) + \delta E_m \quad (2)$$

The hydraulic energy results from:

$$E_h = \frac{p_2 - p_1}{\rho} + \frac{\left(\frac{Q}{A_2}\right)^2 - \left(\frac{Q}{A_1}\right)^2}{2} + g \cdot (z_2 - z_1) \quad (3)$$

The pump total head is given by:

$$H = \frac{p_2 - p_1}{\rho \cdot g} + z_2 - z_1 + \frac{\left(\frac{Q}{A_2}\right)^2 - \left(\frac{Q}{A_1}\right)^2}{2 \cdot g} \quad (4)$$

The flow rate results from the equation:

$$Q = \frac{\eta_p \cdot P_W \cdot \eta_e}{\rho \cdot g \cdot H} \quad (5)$$

The flow rate is determined iteratively, from equations 5 and 1 and from an initial estimate.

Description of the experimental installation and of the measuring instruments

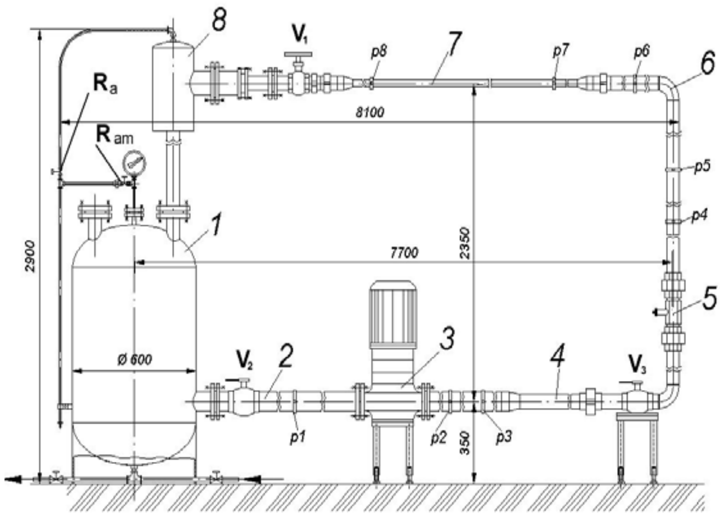

Figure 1. Multifunctional installation in closed loop (without the measuring instruments)

The installation contains the following parts:

1- A suction buffer water tank with a capacity of 200 l which represents a reserve of liquid for taking up the heat resulted from the hydraulic losses so that the temperature of the working liquid to raise relatively slow

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

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.

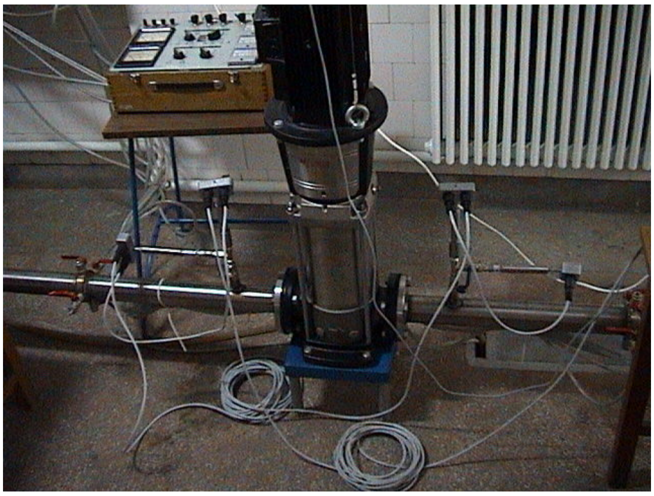

Figure 2. Connection of the pressure and temperature probes for the pump testing

The equipment P22F based on the thermodynamic method is used to determine the efficiency and the flow rate of the tested pump. For this equipment 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.

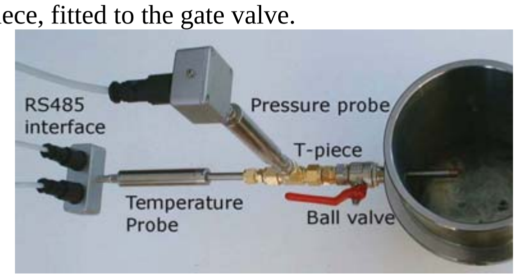

Figure 3. The pressure and temperature probes

The temperature probe tips are made from copper, to improve heat transfer and the accuracy of temperature measurement. The temperature probe calibration is valid over the range 0-45°C. These probes are for use in thermowells only. The thermowell is angled downwards, so light machine oil is added to displace the air, and improve thermal conduction.

The pressure sensor is manufactured by Keller. The calibration is referenced to atmospheric pressure (gauge). The inlet (suction) pressure probe has a range of 0 - 2.5 bar. The outlet (discharge) pressure probe has a range of 0 - 15 bar. The calibration is most accurate over the range 0 - 40°C.

Measured data with the thermodynamic method and analyses of the results

The equipment P22F measures with the pressure and temperature probes the pressure and temperature upstream and downstream the pump and calculates the following data:

- Pressure difference between outlet and inlet of the pump

- Temperature difference between outlet and inlet of the pump
- Pumping head
- Pump efficiency
- Flow rate of the pump

The measuring errors which could appear can be corrected through specific settings of the equipment software. The data measured and calculated are stored in an EXCEL file from where they could be analyzed after.

The tests were made at 3 different rotational speeds.: n_1=2900 rot/min as a maximum reference speed (100%), n_2=2320 rot/min (80%) and n_3=1740 rot/min (60%).

Table 1. Flow rate and efficiency for different rotational speeds

Nr. crt.	n (rot/min)	Q(l/s)	η(%)	n (rot/min	Q(l/s)	η(%)	n (rot/min	Q(l/s)	η(%)
1	2910	0.59	12.15	2310	0.57	17.24	1740	0.46	14.19
2		1.01	19.7		1.27	29.34		0.91	26.26
3		1.82	32.8		1.86	40.33		1.36	36.32
4		2.51	42.27		2.49	49.47		1.91	45.63
5		3.31	51.47		3.03	55.25		2.49	52.93
6		4.17	58.31		3.53	59.78		3.01	58.02
7		4.71	61.86		4.1	64.17		3.49	61.17
8		5.44	65.92		4.52	66.66		4.05	63.02
9		6.04	68.43		5.01	68.44		4.51	63.46
10		6.67	69.99		5.37	69.37		4.73	63.23
11		7.36	70.49		5.88	69.65		5.02	62.12
12		8.17	70.25		6.53	69.02		5.35	60.32
13		9.01	67.49		6.88	67.84		-	-
14		9.29	66.73		7.4	65.13		-	-

In figure 4 is shown pump efficiency vs. flow rate.

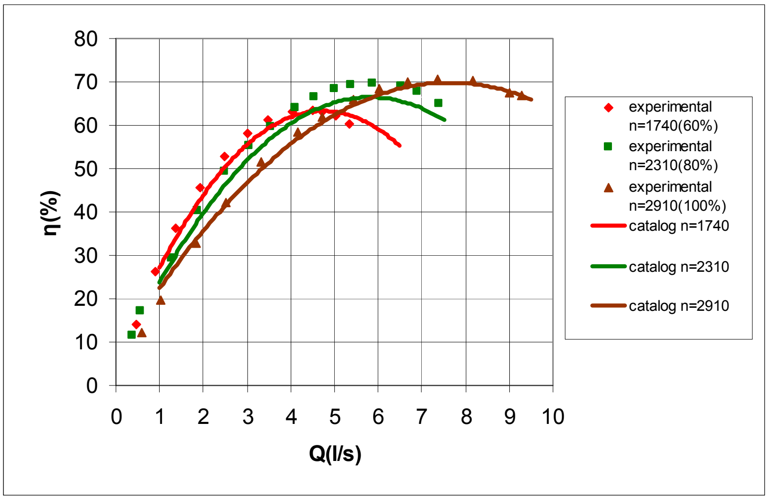

Figure 4. Pump efficiency vs. flow rate, measured and given by the pump producer

The energetic parameters *Q, η* measured using the thermodynamic method were compared with the reference data given by the pump producer. Our experimental results obtained with the thermodynamic method are in a good agreement with reference data. Bigger 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.

Conclusions

- The thermodynamic method it proves to be very efficient and precise in monitoring a pump.
- Using the P22 equipment for the determination of the efficiency and of the flow rate of a centrifugal pump we obtained reliable results which prove that the equipment can be use for future industrial applications.
- Using of the P22 equipment in industrial applications leads to significant energy savings and from that results an important reduction of the exploitation costs.

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