The determination of the flow rate of a Kaplan turbine using the thermodynamic method

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Abstract

This paper presents the determination of the flow rate of a Kaplan turbine with an equipment using the thermodynamic method. The thermodynamic method is used mainly to determine the efficiency of hydraulic turbine and pumps. This method is recommended for testing the hydraulic turbines by IEC 60041. It began to be used in 1950, but because of the low performance of the equipment used the application of this method was drastic restrained. The advance of the technology in the last 10 – 20 years allowed the application of this method to turbines with heads smaller than 20 m. Although the thermodynamic method is used to determine the efficiency, the flow rate of the turbine results from the application of the energetic balance to the turbine. The flow rate obtained with this method is important in order to determine the exploitation characteristic of the investigated turbine. The simplicity of this method in comparison with other methods is that it is needed to measure only the pressure and temperature upstream and downstream of the turbine in order to obtain the flow rate.

Nomenclature

p_{abs1}, p_{abs2} [N/m^2]- absolute pressure in measuring sections upstream and downstream of the turbine

T_1, T_2 [K]- water temperature in measuring sections upstream and downstream of the turbine

v_1, v_2 [m/s]- velocities in measuring sections upstream and downstream of the turbine

z_1, z_2 [m]- elevation of the measuring section upstream and downstream of the turbine regarding a reference plane

δE_m [J/kg] - correction factor due to imperfect measuring conditions and secondary phenomenon

$\bar{a}$ [m^3/kg]- isothermal coefficient of the water

c_p [J/(kg·K)]- specific heat of the water

ρ [kg/m^3] – density of water

Q [m^3/s]– flow rate

H [m]– head of the turbine
E_m [J/kg]– specific mechanical energy
η_{ht} [-]– hydraulic efficiency of the turbine
P_m [W]– mechanical power
P_h [W]– hydraulic power
P_{eg} [W]– power of the electrical generator
η_{eg} [-] – efficiency of the electrical generator
P_t [W]– power of the turbine
a_0 [%]– relative position of the guide vanes

Introduction

The Hydraulic Machinery Laboratory of "POLITEHNICA" University of Timisoara has a the portable equipment P22F for the measurement of the energetic parameters of a hydraulic machine, based on the thermodynamic method. In order to set a general testing method, which can be applied to any hydraulic machine, a case study was released on a turbine from a test facility at the Hydraulic Machinery Laboratory and after that on a Kaplan turbine from a hydropower plant.

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 $J \cdot kg^{-1}$ (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 turbines with smaller specific hydraulic energy.

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

$$\eta_{ht} = \frac{P_m}{P_h} = \frac{E_m}{E \pm \frac{\Delta P_h}{P_m} \cdot E_m} \qquad (1)$$

The thermodynamic method allows the direct measuring of specific mechanical energy which is linked by definition to P_m through the equation:

$$P_m = \rho \cdot Q \cdot E_m \qquad (2)$$

The specific mechanical energy is given by the equation:

$$E_m = E_{1-2} = \bar{a} \cdot \left(p_{abs1} - p_{abs2}\right) + \bar{c}_p \cdot \left(T_1 - T_2\right) + \frac{v_1^2 - v_2^2}{2} + g \cdot \left(z_1 - z_2\right) + \delta E_m \qquad (3)$$

The flow rate results from the equation:

$$Q = \frac{P_t}{\rho \cdot g \cdot H \cdot \eta_{ht}} \tag{4}$$

where H and η_{ht} is determined with the thermodynamic method and P_t is obtained by measuring P_{eg} and considering the efficiency of the electric generator:

$$P_t = P_{eg} \cdot \eta_{eg} \tag{5}$$

The equipment and methodology used to determine the flow rate with the thermodynamic method

The equipment P22F based on the thermodynamic method is used to determine the flow rate of the turbine. The temperature and pressure upstream and downstream of the turbine is measured with high performance specialized probes. For the measuring of the pressure and temperature difference across the turbine tapping points are required on the inlet and outlet of the turbine.

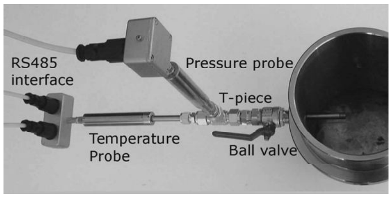

Fig.1 The pressure and temperature probes

Because the existing conditions at the measuring site, it was impossible to install the pressure and temperature probes in the correct way. The probes were installed on the free surface of the water upstream and downstream of the turbine.

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

- Pressure difference between inlet and outlet of the turbine
- Temperature difference between inlet and outlet of the turbine
- Turbine head
- Turbine efficiency
- Flow rate of the turbine

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.

Measured data with the thermodynamic method and analyses of the results

For the calibration of the method some preliminary tests were made on a Kaplan turbine from the Hydraulic Machinery Laboratory of "POLITEHNICA" University of Timisoara. The results are presented in figure 2.

For the investigated turbine from the hydropower plant the pressure and temperature difference on the free surface upstream and downstream of the turbine was measured and the other data needed for the flow rate determination was taken from the commanding panel of the turbine. The measurements were conducted at a constant head of 23,8 m for 7 different charges of the turbine. In the figure 3 are presented the data resulted from the measurements with the thermodynamic method on the Kaplan turbine:

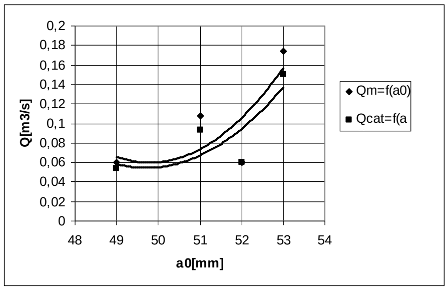

Fig. 2 Flow rate of the Kaplan turbine from the laboratory

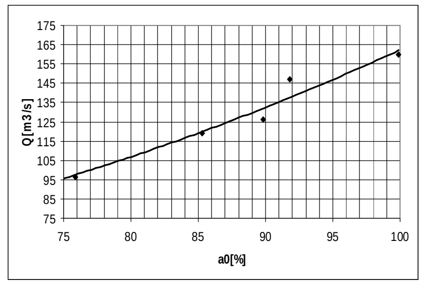

Fig. 3 Flow rate of the Kaplan turbine from the hydropower plant

Conclusions

- The rate of error of the flow rate measurements for the turbine from the laboratory appear because the very small head realized in the laboratory
- The thermodynamic method used to determine the flow rate can be applied to a Kaplan turbine with a relative small head
- The effective measuring conditions and the “pollution” of the water downstream the turbine with parasite heat sources like the cooling water of the electrical generator could affect more or less the results. In this case it could not be quantified the influences of the positioning of the probes and the “polluted” heat sources upon the results.
- The correct positioning of the probes upstream and downstream eliminates the influence of the environment and of the “polluted” heat sources and could conduct to the approach of the determined flow rate with the real turbinated flow rate.

References

1. Alming K., Bokko E., - *„A comparison of the Thermodynamic Method at the Beginning and at Present”* Proc. of the International Group for Hydraulic Efficiency Measurements – Montreal 1996.
2. Baya A., Anton, L. E., Miloş T., Stuparu A., - *„Achiziţii şi prelucrări de date în timp real pentru experimente de hidrodinamică”*. Lucrările celei de a treia Conferinţe a Hidroenergeticienilor din România, Bucureşti 2004.
3. *IEC 60041: International code for field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines*. Publication 41, 3rd edition, 1991.
4. Hans P., D., Doering J., C., - *„A Comparison of Discharge Calculation Method*”. Proc. of the International Group for Hydraulic Efficiency Measurements – Montreal 1996
5. Karlicek R., F., - *„Test Equipment and Results from 25 Hydraulic Turbine Tests using Thermodinamic Method”*. Proc. of the International Group for Hydraulic Efficiency Measurements – Montreal 1996.