Testing of a submersible motor-pump group

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Lab 1: Testing of a submersible motor-pump group

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1 Introduction

During the this laboratory session, a motorpump submerged under water was the subject of the experiment. One of its purpose is to drain water from a lower reservoir to a higher reservoir. The motor of the pump is a sealed squirrel cage. This type of motors are chosen due to their robustness and ability to function under water. The pump has five identical stages with components such as centrifugal rotor, a vanned diffuser and outlet channels to avoid vortex. Vortex or cavitation can have severe effects on the performance of the pump, creating bubbles that can reduce the section used by the fluid, even causing fatal damage on the pump. The bears inside the pump that holds different components together, avoiding direct physical contact and friction.

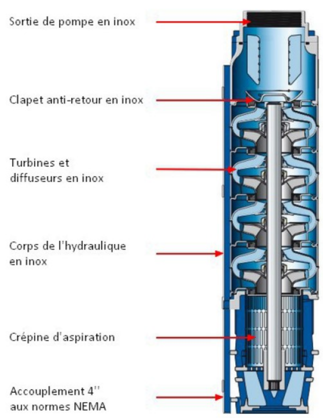

Figure 1: Submersible pump with five stages

1.1 Operational Parameters

In this experiment one has to graphically represent the effect of volumetric flow rate of operational parameters. The operating parameters are as follows.

- the transferred useful specific energy "e"
- the power consumed by the motor "Pmot"
- the efficiency of the pump "ηp"
- the rotational speed "N"

1.2 Description of the Experiment

As mentioned, the submersible pump used for this experiment is made of five identical stages, each one consisting of a narrow, purely centrifugal rotor, a vanned diffuser and outlet channels preventing vortex formation at the entrance of the following stage. The other components of the setup are presented in figure 2 and it is composed by a multistage pump, an electrical motor, an obstruction flow meter, a tachometer, a current meter, a regulation valve and a manometer, a lower reservoir of water and an upper reservoir (or recovery tank).

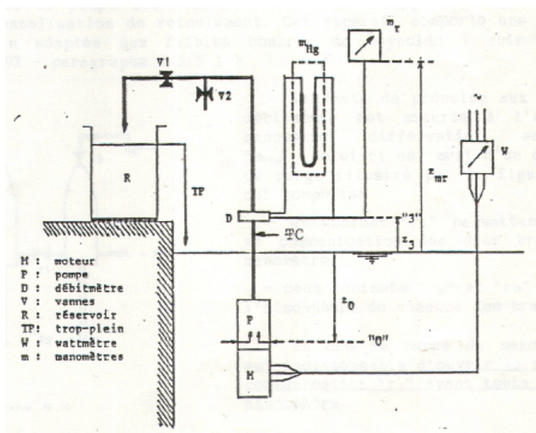

Figure 2: Submersible pump - Laboratory set up

1.3 Formulation and equations

1.3.1 Energy Transfered from the motor

The transferred useful energy "e" of the pump can be deduced by the following equation,

$$\frac{p_{out}-p_{in}}{\rho} + g(z_{out} - z_{in}) + \frac{v_{out}^2 - v_{in}^2}{2} = \frac{p_r}{\rho} + gz_{mr}$$

- P_out and p_in are the static pressures at the outlet and inlet of the pump.
- ρ is the density of water and is equal to 997 kg/m^3.
- g is the gravitational constant and is equal to 9.81m/s^2.
- z_out and z_in are the outlet and inlet heights of the pump.
- z_mr is the height of manometer.
- p_r is the effective pressure indicated on the gauge.
- v_out and V_in are the outlet and inlet flow of the pump

1.4 Volumetric Flow Rate

The Volumetric flow rate is estimated using an obstruction flowmeter that is mounted on the outlet pipping. The pressure difference indicated on the water-mercury manometer is then used to compute the Volume flow rate:

$$q_v[\frac{l}{s}] = 0.0935\sqrt{(l_1 - l_2)[mmHg]}$$

1.4.1 Manometer

It measures effective pressure p_r at a fixed height z_mr above the water level of the lower reservoir. The value obtained is the difference between the pressure of the pump minus the height from manometer height to water level of the lower reservoir:

$$p_r = P_pump - g * \rho * z_mr$$

1.5 Transferred useful specific energy

By analysing the circuit, kinetic energy equation is applied between the point of installation of the manometer and the outlet section of the pump.

$$\frac{v_{out}^2}{2} + \frac{p_{out}}{\rho} + g * z_{out} = \frac{v_{mr}^2}{2} + \frac{p_{mr}}{\rho} + g * z_{mr}$$

Applying kinetic energy equation between the inlet of the pump and free level of water one can get:

$$\frac{v_{in}^2}{2} + \frac{p_{in}}{\rho} + g * z_{in} = \frac{p_{atm}}{\rho}$$

By combining the previous equations and rearranging the energy "e" transferred to the fluid from the pump, one can obtain:

$$\frac{v_{out}^2 - v_{in}^2}{2} + \frac{p_{out} - p_{in}^2}{\rho} + g * (z_{out} - z_{in} = \frac{v_{mr}^2}{2} + \frac{p_{mr} - p_{atm}}{\rho} + g * z_{mr}$$

The manometer effective pressure difference is given by:

$$p_r = p_{mr} - p_{atm}$$

considering velocity to be null at the point of installation of the manometer:

$$v_{mr} = 0$$

the resulting equation becomes:

$$\frac{v_{out}^2 - v_{in}^2}{2} + \frac{p_{out} - p_{in}^2}{\rho} + g * (z_{out} - z_{in} = \frac{v_{mr}^2}{2} + \frac{p_r}{\rho} + g * z_{mr}$$

$$e = g * H = \frac{P_r}{\rho} + g z_{mr}$$

1.6 Mechanical power

The Mechanical Power is computed using the following equation:

$$p_{mech} = \eta_{motor} VIcos\phi$$

It is given for single phase V=230 v_{AC}, cosϕ= 0.91 and efficiency of η=58%. The current is measured by an ampere-meter for each different flow rate. By substituting the given values in the above equation, one can get the maximal mechanical power measured in the experiment $P_{mech_{max}}$= 424.78 W. The values are obtained when the power is lost due to friction and is given by:

$$p_{mech} = P_r + P_f$$

If one neglects the power losses, it is defined the power available at the rotor:

$$P_{mech} = P_r(poweravailableattherotor).$$

1.7 Specific energy

The static specific energy is given by the part of equation $\frac{P_r}{\rho} + gz_{mr}$ while the dynamic specific energy is equal to $\frac{v_s^2}{2}$.So, the total specific energy can be written as:

$$e = \frac{v_s^2}{2} + \frac{P_r}{\rho} + gz_{mr}$$

Where vs is the exit velocity, which is computed using the flow rate and the diameter of the exit section (given value of 96mm).

1.8 Pump efficiency

The pump's efficiency is calculated using the usable power and the mechanical power required to run the pump; the group's efficiency is thus given by the equation:

$$\eta_{group} = \frac{\rho * q_v * e}{p_{mech}}$$

This efficiency is calculated by multiplying the motor's efficiency by the efficiency of one of the pumps. As a result, the pump's efficiency is determined by:

$$\eta_{pump} = \frac{\eta_{group}}{\eta_{motor}}$$

Where η_{motor} is assumed constant and equal to 58%. In theory, the chosen pump must operate at optimum efficiency. It is self-evident that a pump must be operated in operating circumstances that correspond to maximum efficiency or close to it, and that the pump selected is based on the type of circuit in which the pump will be installed and utilized, as well as the demand on that circuit.

2 Results and analysis

Under this section, the results of the calculation together with the figures will be discussed.

2.1 Specific energy

From the specific energy equation, the characteristic curve of the piping network can was obtained applying the principles described in the previous section. The values of the useful specific energy, power consumed by the motor, the efficiency of the pump and the rotational speed are represented in per unit (p.u.) values, for simpler comparison:

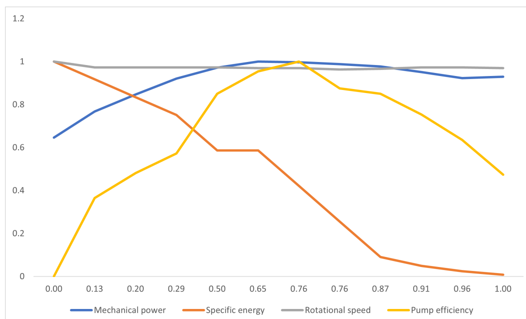

Figure 3: Characteristic parameters of the submersible pump as function of the flow rate

The results and in particular of the specific energy, are similar to the theoretical curves of specific energy discussed in the theory lecture.

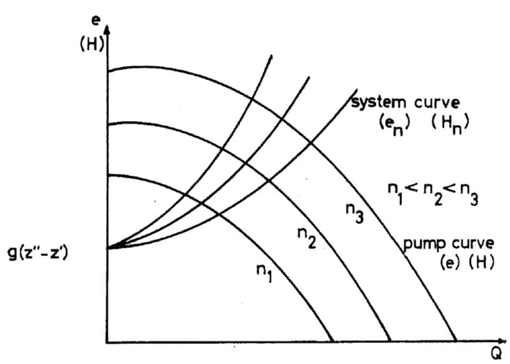

Figure 4: Theoretical pump characteristic curve

The specific energy, is represented with a parabolic shape, being proportional to the square of the flow rate which leads to a polynomial of second order. The highest specific energy is obtained at the lower flow rate.

2.2 Mechanical power

In figure 3 the mechanical power one can see the evolution of it. Based on the theory, it is known that the mechanical power is influence by the friction losses and square of the volumetric flow rate. In this experiment and specific set up, the influence of the friction losses is not very drastic.

2.3 Pump efficiency

In figure 3 the representation of the pump efficiency shows that is maximum value is 48% . This should be consider then the best operating point, with minimum losses.

2.4 Rotational speed

During the laboratory session the rotational speed was very stable as shown under figure 3. Despite this overall assumption, one can see some variations of the speed occur in a mirror distribution with regards to the mechanical power. One of the possible explanations is an inverse relation between the speed and the load consumption of the motor.

3 Conclusion

The operating characteristics are experimentally determined and correspond with the theoretical values. The analysis was done by comparing volumetric flow rate with specific energy, mechanical power, efficiency and speed characteristics of the pump.