

Hands on session N° 2: evaluation of centrifugal pump characteristic curve

a.

Objectives:

- introduce different types of pressure transducers (relative, absolute)
- gather and process experimental data for flow rate and pressure rise through the inlet/outlet section of a centrifugal pump;
- represent dimensional and dimensionless experimental data (pump characteristic curve).

Flow loop

The flow loop used for the experiment is sketched in Figure 1. A 3.0 m^3 capacity tank is used to feed the flow to a centrifugal pump (CALPEDA NM 65/16 AE, maximum flow rate $120 \text{ m}^3/\text{h}$) delivering the fluid through the recirculating loop; at the end of the loop, the fluid is collected back in the same tank.

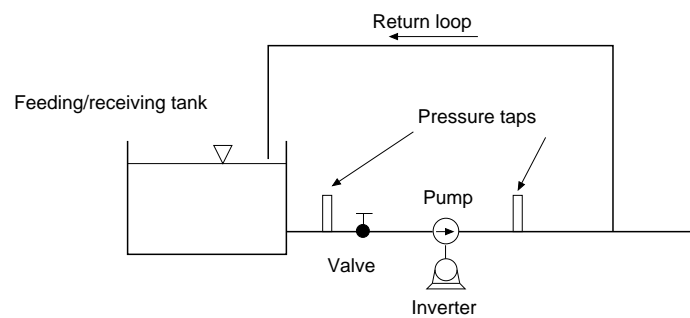


Figura 1. Experimental recirculation loop. V is a regulation valve,; A and B are pressure taps.

The fluid flow rate circulating in the loop depends on the balance between the energy per unit mass delivered by the pump (which is represented by the pump characteristic curve at the corresponding angular velocity, $n = [RPM]$, imposed by the inverter) and the frictional losses along the recirculating path (the pipe operating curve). The working point of the pump is the intersection between the characteristic curve and the operating curve. Pipe diameter and length are fixed; yet, the pipe operating curve can be changed using the valve V : closing the valve, the fluid experiences additional pressure losses which can be associated to an “equivalent” increase of the pipe length. This moves the operating curve toward larger pressure drops and lower flow rates, moving the working point of the pump to a different point along the characteristic curve. In this way, the hydraulic resistance along the loop can be increased, with a corresponding decrease of flow rate circulating in the loop from the maximum deliverable at a fixed pump rotation velocity n (valve V fully open) to zero (valve V fully closed), exploring a number of points along the pump characteristic curve. Different pump characteristic curves can be sampled in this way if the value of n is modified changing the frequency of the inverter (SILCOVERT SVTSplus, AsiRobicon). Pairs of Q circulating in the loop and Δp measured between pump delivery/suction sections can be derived to build experimentally the pump characteristic curve.

Pressure taps

The position of pressure taps used for Δp acquisition is sketched in Figure 2. Pressure upstream the pump (p_A) is measured by a vertical side line connected to pressure transducer PT1. Pressure downstream the pump (p_M) is measured by a vertical side line connected to pressure transducer PT2.

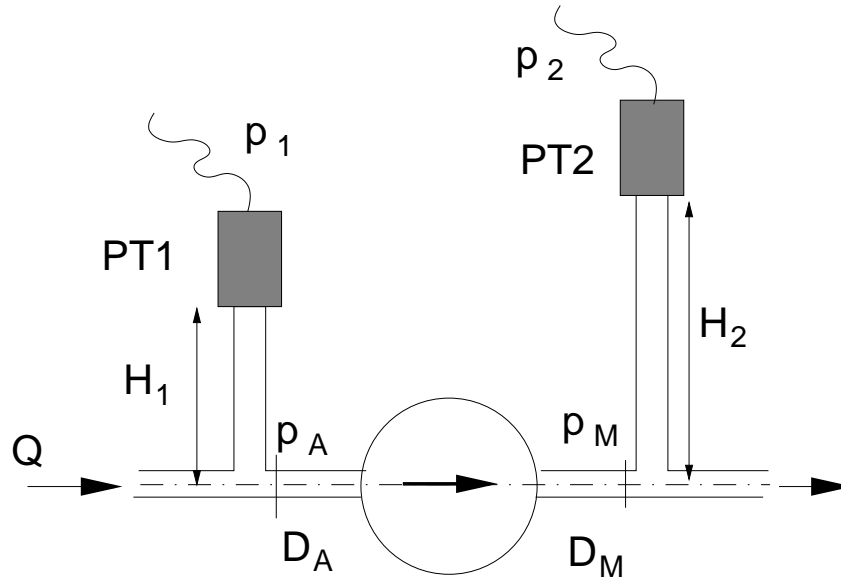


Figura 2. Positions of pressure transducer at upstream/downstream ends of the pump.

Pipe diameter of the upstream side is $D_A = 84.85 \text{ mm}$. Pipe diameter of the downstream side is $D_M = 72.45 \text{ mm}$. Pump impeller diameter is $D_G = 260 \text{ mm}$. Bernoulli equation between the upstream and downstream side of the pump gives:

$$\frac{1}{2}v_A^2 + \frac{p_A}{\rho} + w_s = \frac{1}{2}v_M^2 + \frac{p_M}{\rho} \quad (1)$$

and pump energy per unit mass is

$$w_s = \frac{p_M - p_A}{\rho} + \frac{1}{2}v_M^2 - \frac{1}{2}v_A^2 \quad (2)$$

Values of p_A and p_M are unknown, whereas we can measure with the pressure transducers p_1 and p_2 . Bernoulli equations between 1-A and 2-M give:

$$p_1 + \rho g H_1 = p_A \quad (3)$$

$$p_2 + \rho g H_2 = p_M \quad (4)$$

and substituting for p_M and p_A the values measured by pressure transducers we get:

$$w_s = \frac{p_2 - p_1}{\rho} + g(H_2 - H_1) + \frac{1}{2}v_M^2 - \frac{1}{2}v_A^2 \quad (5)$$

Pump energy per unit mass can be written as pump head

$$H = \frac{w_s}{g} \quad [m] \quad (6)$$

Acquisition of flow rate and pressure data

1. Monitored data are:

- Flow rate, $[m^3/h]$
- Pressure at PT1, upstream the pump (Absolute pressure), $[mbar]$
- Pressure at PT2, downstream the pump (relative to environment), $[bar]$

2. Check of the accuracy of pressure sensors

To check if the sensors are calibrated properly, we can compare the difference of pressure measured when the fluid is not flowing along the line. Before starting and after ending the data monitoring, we can check:

- the value of atmospheric pressure (to transform the value of relative pressure monitored by PT2 into an absolute value)
- the value of pressure monitored by PT1 and PT2 in no-flow conditions (null value)

The vertical distance between PT1 and PT2 ($H_2 - H_1$) is 300 mm. The difference in static pressure (measured at no flow condition) is given by the static head of 300 mm H_2O , i.e.:

$$p_1 = p_2 + 300mm H_2O + C \quad (7)$$

where C ($\neq 0$) is a correction factor necessary to align the measurements if the sensors are not properly calibrated. The value of C is summed, with its sign, to the experimental values recorded as p_2 .

Values of p_1 and p_2 to calculate C are those measured when the pump is switched off.

Since misalignment between sensor can drift during the tests, null values are evaluated at the beginning and at the end of the test, and their average value is taken for correction. This value is used to correct p_1 (or p_2) monitored during the tests.

Values of p_2 (PT2), which are relative to the environment, must be converted into absolute values using the mean value of environmental pressure (average between begin/end of test period).

Equations to be used to correct the raw values of pressure read from transducers are:

$$p_{1c} = p_{1r} + \frac{\Delta zero_A}{2} \quad (8)$$

$$p_{2c} = p_{2r} + \frac{\Delta zero_M}{2} + p_{atm} + C \quad (9)$$

where subscripts $_c$ and $_r$ stand for “corrected” and “raw”. Given the flow rate Q , the flow velocity upstream and downstream the pump are

$$c_A = \frac{4Q}{\pi D_A^2} \quad (10)$$

$$c_M = \frac{4Q}{\pi D_M^2} \quad (11)$$

3. Dimensionless form of pump characteristic curves obtained at different values of n

To represent into a compact form the pump characteristics curve ($H = f(Q)$) evaluated for the pump at three different n [RMP], we define two dimensionless parameters

- Flow number

$$\varphi = \frac{Q}{\omega D_G^3} \quad (12)$$

- Pressure number

$$\psi = \frac{gH}{\omega^2 D_G^2} \quad (13)$$

where:

$$\omega = \frac{2\pi n}{60} \quad (14)$$

and D_G is the pump impeller diameter. In the plot $\psi = f(\varphi)$, the pump characteristics curve obtained for n_1 , n_2 and n_3 should overlap.