# Hands on session N$^o$ 2:
# 2.1 Evaluation of centrifugal pump characteristic curve

*a.* ______________________________

**Objectives:**

- gather and process experimental data of 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 tank is used to feed the flow to a centrifugal pump (PEDROLLO NGA1Am, maximum flow rate 350 $L/min$, power 0.75 kW) delivering the fluid through the recirculating loop; at the end of the loop, the fluid is collected back in the same tank. The fluid flow rate circulating

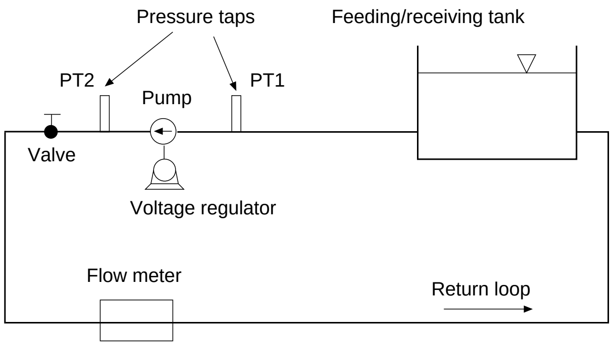


Figura 1: Experimental recirculation loop. $V$ is a regulation valve; PT1 and PT2 are two pressure taps placed upstream and downstream the pump (to measure pressure at the suction and delivering sections).

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 evaluated at the given angular velocity, $n = [RPM]$, fixed by the voltage regulator) and the frictional losses along the recirculating path (the loop 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 loop 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 $n$ (when the valve V is fully open) to zero (when valve V is fully closed), and we can explore a number of pump operating points along the pump characteristic curve. Changing the supply voltage powering the pump, $V_{nom}$, by mean of the voltage regulator (Variac), the pump angular rotation velocity $n$ can be changed. The pump characteristic curve obtained for a different value of $n$ can be sampled as before. For each fixed value of $n$, pairs of $Q$ circulating in the loop and $\Delta p$ measured between pump delivery, $p_M$ and suction, $p_A$, sections can be derived from the data to build experimentally the pump characteristic curve.

## Pressure taps

The position of pressure taps used for $\Delta p$ acquisition is sketched in Figure 2. Pressure upstream the pump ($p_A$) can be calculated from the pressure measured at the top of a vertical side line connected to pressure transducer PT1 ($H_1 = 18$ $cm$). Pressure downstream the pump ($p_M$) can be calculated from the pressure measured by a pressure transducer PT2 placed at the end of a horizontal side line ($H_2 = 38$ $cm$ above the pump delivering section). The internal diameter of the upstream and downstream pipe connected to the pump is $D_A = D_M = 41.8$ $mm$. Pump


☺2016 marina.campolo@uniud.it

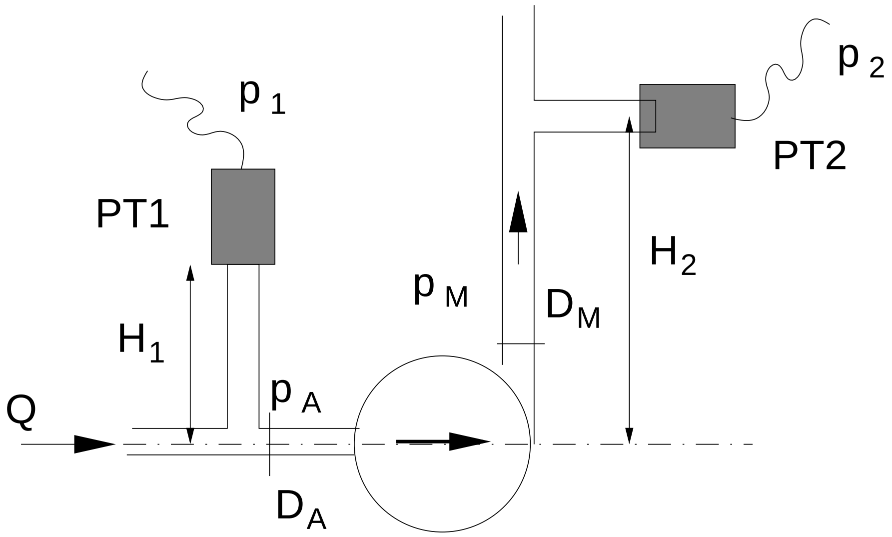


Figura 2: Positions of pressure transducers used to measure pressure at upstream/downstream ends of the pump.

impeller diameter is $D_G = 122\ mm$. Bernoulli equation between the upstream and downstream side of the pump gives:

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

and since $v_A = v_M$, pump energy per unit mass is

$$w_s = \frac{p_M - p_A}{\rho} \tag{2}$$

Values of $p_A$ and $p_M$ are unknown, whereas we measure $p_1$ and $p_2$ with the pressure transducers. Bernoulli equations between 1-A and 2-M (there is no flow in 1-A and in 2-M) give:

$$p_1 + \rho g H_1 = p_A \tag{3}$$
$$p_2 + \rho g H_2 = p_M \tag{4}$$

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

$$w_s = \frac{p_2 - p_1}{\rho} + g(H_2 - H_1) \tag{5}$$

Pump energy per unit mass can be written as pump head, i.e. equivalent height at which a pump can raise water up,

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

**Acquisition of flow rate and pressure data**

1. Monitored data are:

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

We assume the environmental pressure is equal to $p_{env} = 1\ bar = 1000\ mbar$.

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 through the pump. We can check the value of pressure difference monitored between PT1 and PT2 in no-flow conditions (null value) which should be equal to the difference of static pressure between points A and M The vertical distance between PT1 and PT2 ($H_2 - H_1$) is 200 $mm$. The difference in static pressure (measured at no flow condition) should be 200 $mm\ H_2O$, i.e.$\simeq$ 20 $mbar$:

$$p_1 = p_2 + 200mm\ H_2O + C \tag{7}$$

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.

Values of $p_1$ (PT1), which are absolute values are converted into relative values using the reference value of environmental pressure (1000 mbar) during real time acquisition and before file data recording.

The Equation to be used to calculate the corrected value of pump head is:

$$w'_s = \frac{p_2 - p_1}{\rho} + g(H_2 - H_1) + \frac{C}{\rho} \tag{8}$$

$$H = \frac{w'_s}{g} \quad [m] \tag{9}$$

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 two different $n$ $[RMP]$, we define two dimensionless parameters

- Flow number

$$\varphi = \frac{Q}{\omega D_G^3} \tag{10}$$

- Pressure number

$$\psi = \frac{gH}{\omega^2 D_G^2} \tag{11}$$

where:

$$\omega = \frac{2\pi n}{60} \quad [1/s] \tag{12}$$

is the angular velocity of the pump in $1/s$ and $D_G$ is the pump impeller diameter. In the plot $\psi = f(\varphi)$, the pump characteristics curve obtained for $n_1 = 2830\ RPM$ ($V = 240\ V$) and $n_2 = 2710\ RPM$ ($V = 200\ V$) should overlap.