FLUID FACILITIES AND MACHINERY

GUIDE TO LABORATORY PRACTICALS

University of the Basque Country (UPV/EHU)

Energy Engineering Department

THEME 2: PUMPS 2: ROTATION SPEEDS

1. REQUIRED BACKGROUND KNOWLEDGE

Fluid Mechanics.

Hydraulic Machinery. Turbomachinery. Pumps.

2. PRE-LABORATORY

Detailed reading of the description of the practical for its completion within 1 [h]. See Video of P2.

3. OBJECTIVES

To calculate and to demonstrate the operation of a pump at different rotation speeds:

- Visual observation of the operation of one pump.
- Experimental determination of the characteristic curves of pump performance for a pump operating at different rotation speeds.
- Comprehension and comparison of the ***H*-*Q*** characteristic curves obtained in the laboratory, with the curves obtained by means of Similitude laws. Comprehension and comparison of the mechanical power and the yield curves that are experimentally obtained.

4. THEORETICAL FOUNDATION

As explained in the previous section corresponding to Practical 1, the most widely used characteristic curve of a hydraulic pump relates the height, ***H***, to the flow rate, ***Q***, that it supplies at a specific rotation speed. The real curve is defined as a parabolic function $H = A + B \cdot Q + C \cdot Q^2$, rather than a linear (theoretical curve), due to losses and the existence of a finite number of vanes, as previously shown in Figure 1, corresponding to Practical 1.

Through a purely theoretical analysis, the mathematical expression of the corresponding characteristic curve for each specific case cannot be obtained. In general, the curve is determined experimentally on a test bench and it will also appear in the product specifications supplied by the pump manufacturer.

When designing facilities, the performance of the pump and that of the facility as a whole must be taken into account. To do so, the powers and the yields that characterize a facility are defined below:

- Hydraulic power: The power gained by the liquid that is defined as: $\boldsymbol{P_h = \rho \cdot g \cdot Q \cdot H}$
- Mechanical power or external power of the shaft of the pump: $\boldsymbol{P_m = M \cdot N}$
- Electrical power: the data on the electrical consumption of the pump motor: $\boldsymbol{P_e}$

The torque, ***M***, can be measured by means of a dynamometric brake, as detailed below, and the rotational speed, ***N***, by means of a tachometer. The different yields are specified in accordance with the previously defined powers:

- Overall efficiency of the pump: $\boldsymbol{\eta_{G.B.} = P_h/P_m}$
- Overall efficiency of the engine: $\boldsymbol{\eta_{G.M.} = P_m/P_e}$
- Overall efficiency of the pump-engine system: $\boldsymbol{\eta_{G.M.\text{-}B.} = \eta_{G.B.} \cdot \eta_{G.M.} = P_h/P_e}$

Thus, the characteristic curve, the overall efficiency of the pump, and both the hydraulic power and the mechanical power, can be represented as follows (Figure 6):

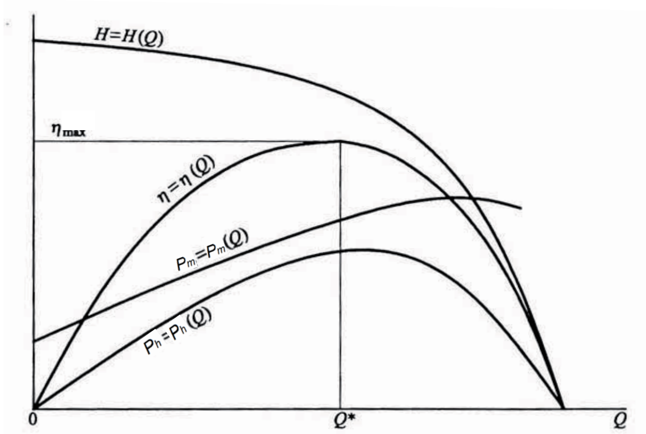

Figure 6: *Evolution of the manometric height, overall efficiency of the pump, shaft or mechanical power, (P_m), and hydraulic power, (P_h), as a function of the flow.*

As shown in Figure 6, there is always some consumption once the pump is turned on, even if no fluid is pumped. Therefore, the fitting of the shaft or mechanical power curve, P_m, will be a second-order polynomial:

$$P_m(Q) = D + E \cdot Q + F \cdot Q^2$$

In turn, the hydraulic power, P_h, can be fitted to a curve with the following equation:

$$P_h(Q) = G \cdot Q + H \cdot Q^2$$

The previously defined efficiencies can be fitted with the following expression:

$$\eta(Q) = I \cdot Q + J \cdot Q^2$$

The pump works better when operating at its nominal power, which should correspond to the design flow rate Q^* (see Figure 6), but also within a range of flows close to the optimal flow rate, at which its performance is satisfactory.

Similitude Laws are used to predict the operation of the pump under other conditions, such as rotating at a different rotation speed. Therefore, R_N is defined as the relationship between the known speed of rotation, (**N**), and the desired speed of rotation, (**N'**):

$$R_N = N'/N$$

In addition, according to the Laws of Similitude, the mathematical expressions that relate manometric height, flow rate, power, and efficiency with rotation speed are as follows:

$$\frac{H'}{H} = \left(\frac{N'}{N}\right)^2 = R_N^2$$

$$\frac{Q'}{Q} = \frac{N'}{N} = R_N$$

$$\frac{P'}{P} = \left(\frac{N'}{N}\right)^3 = R_N^3$$

$$\eta = \eta'$$

Applying the corresponding Laws of Similitude, the curves of a pump similar to the one given above can be obtained, operating at different rotation speeds:

$$H' = \mathrm{A}\cdot R_N^2 + \mathrm{B}\cdot R_N \cdot Q' + \mathrm{C}\cdot Q'^2$$

$$P_m' = \mathrm{D}\cdot R_N^{\ 3} + \mathrm{E}\cdot R_N^{\ 2}\cdot Q' + \mathrm{F}\cdot R_N \cdot Q'^2$$

$$P_h' = \mathrm{G}\cdot R_N^{\ 2}\cdot Q' + \mathrm{H}\cdot R_N \cdot Q'^2$$

$$\eta' = \mathrm{I}\cdot\left(\frac{1}{R_N}\right)\cdot Q' + \mathrm{J}\cdot\left(\frac{1}{R_N}\right)^2\cdot Q'^2$$

Once again using the Laws of Similitude, instead of repeating the entire experimentation process on a test bench, the curves of the same pump operating under other conditions (at other rotation speeds) can be calculated based on the curves obtained under certain conditions.

5. DESCRIPTION OF EQUIPMENT AND FACILITY

The Fluid Mechanics laboratory is equipped with a hydraulic bench that has two pumps installed. This bench is equipped with the following basic elements (Figure 7):

Where,

1. Rotation speed digital indicator [r.p.m.].
2. Control panel.
3. Wattmeter monitoring the constant rotational speed of the centrifugal pump [r.p.m.].
4. Main switch.
5. Emergency stop.
6. Variable frequency drive.
7. Wattmeter of the variable rotational speed of the centrifugal pump [r.p.m.].
8. Display selector of [r.p.m.] (B.1 or B.2).
9. Switch of the centrifugal pump (fixed rotational speed).
10. Bourdon type manometer-vacuum gauge.
11. Flow rate regulation valve (impulsion).
12. Centrifugal pump.
13. Switch of the centrifugal pump with rocker engine and variable rotational speed.
14. Dynamometer.

15. Centrifugal pump with rocker engine and variable rotational speed.
16. Rush switch.
17. Aluminium profiles bench.
18. Tank.
19. Ball valves.
20. Shut-off valves

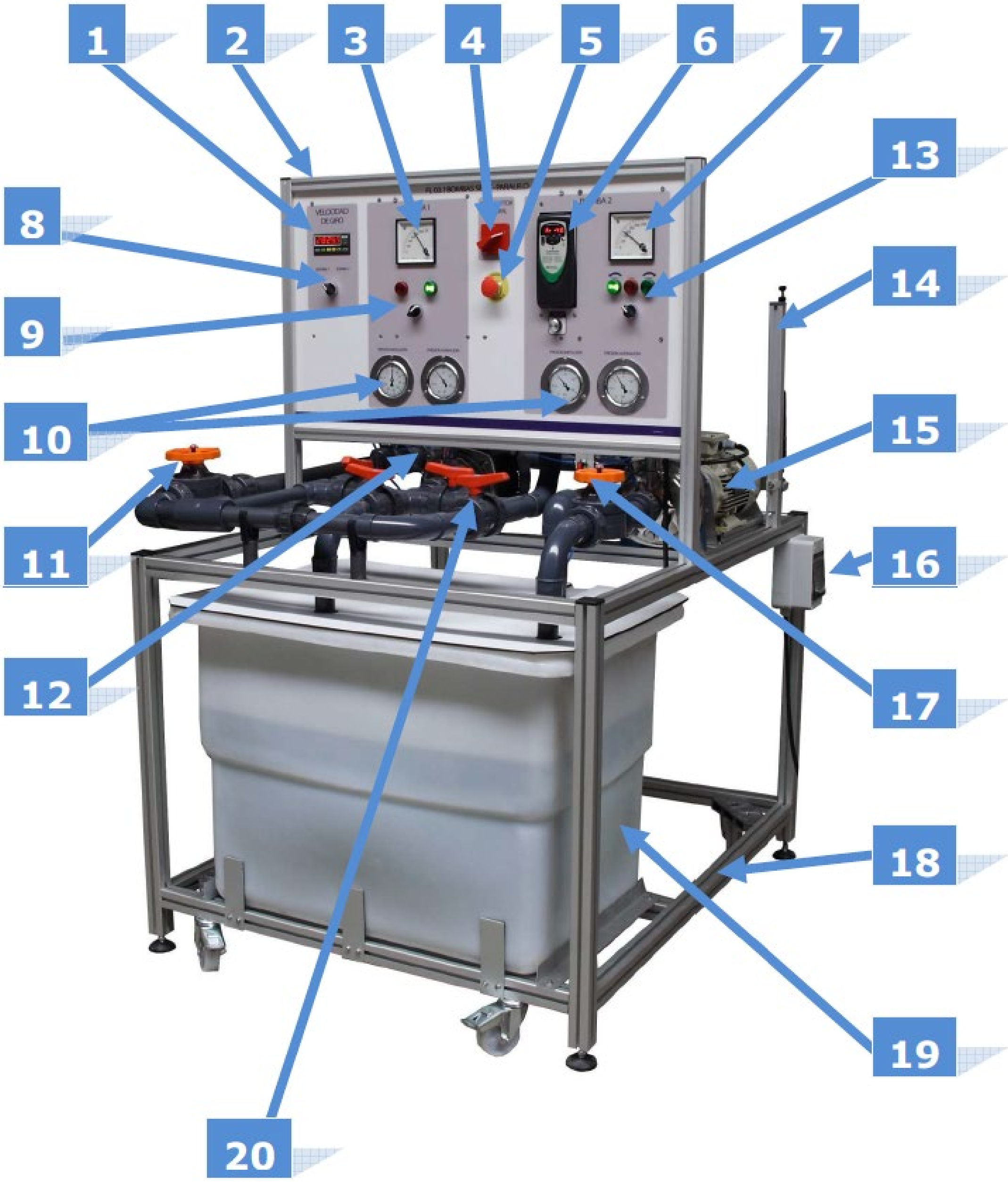

Figure 7: *Hydraulic bench*.

Pump B.2 has a frequency inverter (6) in the supply line that allows its rotation speed to be modified. Pump B.1 has no frequency inverter. The bench has a digital flow meter [m^3/h].

The torque transmitted by the engine of the variable speed pump is measured using the dynamometer alongside it (Figure 8). The dynamometer must first be adjusted to zero by matching the profiles, in order to use it properly: the profile (a fixed metal plate) is located on the vertical bar and is positioned at the end of the pump shaft (the metallic plate is fixed to the pump shaft that can be moved). To do so, the following steps must be taken:

- With the pump stopped, the black knob located on the aluminium profile (1) is loosened, sliding the rod until the two profiles coincide. At that point, the system is in equilibrium, as no torque is transmitted by the engine of the pump and the measurement of the manometer will therefore be equal to zero.
- The scale of the dynamometer must be adjusted to zero, for which purpose the black nut (2) on the top of the dynamometer is adjusted.

Zero will therefore correspond to the horizontal position of the pump at which point no force is exerted on the dynamometer.

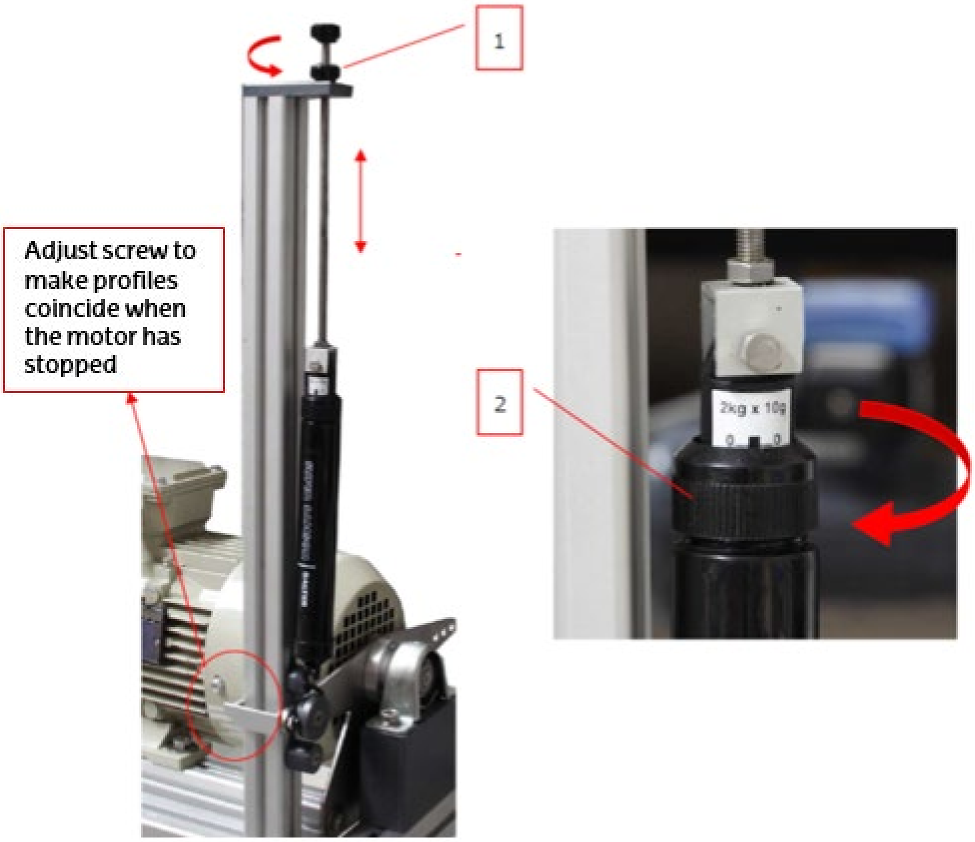

Figure 8: *Dynamometer and rocker arm.*

When both are positioned at the same level, the system will be in equilibrium. The arm, from the dynamometer to the pump shaft, measures 0,110 [m]. Finally, the bank has a set of pipes and connection taps for different practices, as well as a water tank in its lower part (Figure 9).

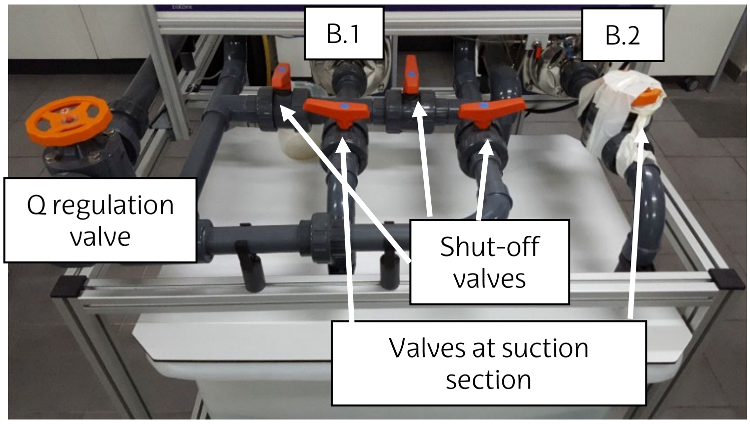

Figure 9. *Pipes, valves, and lower water tank.*