

Characteristic curves of centrifugal pump

Fraňšek Hovorka, Michal Kordač

I Basic relations and definitions

Centrifugal pumps are mainly used for transport of liquids. Knowledge of characteristic curves of centrifugal pumps provides us with information about operating efficiency and can help us with selection of a suitable pump.

The characteristic of centrifugal pump is the dependence between transport depth H_C^+ (sum of suction and discharge heights) and volumetric flow of the liquid through the pump \dot{V} (power input) under constant rotation speed n . A universal characteristic of a pump is a set of characteristics of the chosen pump for different rotation speeds. These characteristics are usually plotted in graphical form and they are supplemented with curves of dependence of power input of the pump P_c and the pump efficiency η_c on volumetric flow of the transported liquid \dot{V} at various rotation speeds n . In the graph of universal characteristic, curves of constant efficiency are also plotted.

Behaviour of these curves is different for each pump and depends not only on pump construction but also on workshop production and on properties of transported liquid.

Reliable basis for their construction is possible to obtain only experimentally. Pipeline with the pump is described by Bernoulli equation between cross sections 1 and 2

$$\frac{p_1}{\rho} + \frac{v_1^2}{2} + h_1 g + e_c = \frac{p_2}{\rho} + \frac{v_2^2}{2} + h_2 g + e_{dis1,2} \quad (1)$$

Liquid is transported in the direction from the cross section 1 to the cross section 2, p is pressure, v is average velocity, g is acceleration of gravity and ρ is liquid density.

The term e_c is the energy per unit mass required so that fluid flows through pipe. The term $e_{dis1,2}$ represents dissipative energy per unit mass between the cross sections 1 and 2. Instead of e_c , the transport height is usually used as follows:

$$H_C^+ = e_c / g \quad (2)$$

While the physical interpretation of the pump energy is clearly determined, in the case of interpretation of the transport height it is necessary to know other conditions of the liquid flow in the pipeline. Therefore it is easier to use Eq. (2) which says that H_C^+ is directly proportional to the pump energy.

Pump power output N_c can be described as output power fully transmitted to the transported liquid in the form of mechanical energy

$$N_c = e_c \dot{m} = H_C^+ g \dot{V} \rho \quad (3)$$

Pump power input P_c represents mechanical power input supplied to the pump shaft by driving unit. Its value can be calculated from the measured power input of the driving electromotor P_{el} by multiplying P_{el} with known electromotor efficiency η_{el}

$$P_c = P_{el}\eta_{el} \quad (4)$$

Pump efficiency η_c is the ratio between power output and power input

$$\eta_c = N_c/P_c \quad (5)$$

Pump head H_C^+ can be determined from Eqs. (5-1) and (5-2) based on measurement of pressure, liquid velocity and geometrical height in cross sections 1 and 2 selected in input and output of the pump. Differences between velocities of the liquid and geometrical heights can be in our case neglected, i.e. $v_1 \cong v_2$ and $h_1 \cong h_2$. Dissipative energy for cross section closely at the beginning and the end of the pump is $e_{dis1,2} \cong 0$, therefore

$$H_C^+ = \frac{p_2 - p_1}{\rho g} \quad (6)$$

Volumetric flow rate of the liquid through the pump \dot{V} is taken by measurement of the flow through electromagnetic flowmeter.

In case we assume similarity of centrifugal pump we can determine dimensionless groups (criteria) for the purpose of conversion of operation conditions of centrifugal pumps. In application of these groups for each individual pump as in this laboratory work for different rotation speed n condition similarity is fulfilled. Therefore value of dimensionless groups doesn't change.

Criteria can be as follows

a) *dimensionless volumetric flow*

$$\Pi_V = \frac{\dot{V}}{d^3 n} \quad (7)$$

b) *dimensionless transport overpressure*

$$\Pi_{\Delta p} = \frac{\Delta p}{d^2 n^2 \rho} \quad (8)$$

c) *dimensionless power input*

$$\Pi_P = \frac{P_c}{d^5 n^3 \rho} \quad (9)$$

In these equations, d is diameter of the pump rotor. Using definitions (7) to (9), it is possible to convert measured pump characteristic curves to the other conditions (e.g. to different rotation speed or to different diameter of the pump rotor).

If there is no pump with suitable characteristics, it is possible to connect two or more pumps in suitable flow scheme. If the pump head is not sufficient, pumps will be connected in series. The head of the pump series is calculated from equation (10), the total flow rate remains unaffected. If the

pumps do not provide sufficient flow rate, pumps connected in parallel will be used. Total flow rate is then calculated from equation (11), while the total head of the pumps remain unaffected.

$$H_{C,A+B}^+ = H_{C,A}^+ + H_{C,B}^+ \quad (10)$$

$$\dot{V}_{A+B} = \dot{V}_A + \dot{V}_B \quad (11)$$

II Aims

1. For given speeds of pump A and B measure and plot graphically following dependences:

- dependence of pump head on volumetric flow rate: $H_C^+ = H_C^+(\dot{V})$
- dependence of pump power input on volumetric flow rate: $N_C = N_C(\dot{V})$
- dependence of pump efficiency on volumetric flow rate: $\eta_C = \eta_C(\dot{V})$

Number of curves in each graph corresponds to number of set values of rotation speeds.

2. From dependencies $H_C^+ = H_C^+(\dot{V})$ for highest value of rotation speed of pump A calculate dimensionless groups and use them for recalculation of H_C^+ for lowest value of rotation speed. Plot the results into the graph (from point 1.a for pump A) together with dependence $H_C^+ = H_C^+(\dot{V})$ obtained experimentally.

3. From dependencies $H_C^+ = H_C^+(\dot{V})$ for lowest value of rotation speed of pump A calculate dimensionless groups and use them for recalculation of H_C^+ for higher rotation speed of pump B. Plot the results into the graph (from point 1.a for pump B) together with dependence $H_C^+ = H_C^+(\dot{V})$ obtained experimentally.

4. Experimentally determine dependency $H_C^+ = H_C^+(\dot{V})$ the two pumps A and B connected in series for given rotation frequencies. Plot the results into a graph along with a characteristics obtained from equation (10). In the calculation use the experimentally determined pump characteristics of both pumps.

5. Determine experimentally dependency $\dot{V} = \dot{V}(H_C^+)$ for the two pumps A and B connected in parallel. Plot this dependency into a graph and compare it with the one obtained using eq. (11). In the calculation, use experimental pump characteristics of both pumps.

Remark: In the laboratory task, You will be asked to verify experimentally only some of the above mentioned points.

III Apparatus description

Flow diagram of the apparatus used for this work is given in fig. 1. The apparatus consists of storage tank **13**, to which two centrifugal pumps **4**, **5** are connected. Pump A has impeller diameter of 85 mm, pump B has impeller diameter of 98mm. It is possible to change the connection of the two pumps using the valves **14**. At the pump setup outlet is electromagnetic flow meter **10** and at its output is a membrane valve for setting the flow rate. The head of the pump is measured by pressure

transducers **5** and **9**.

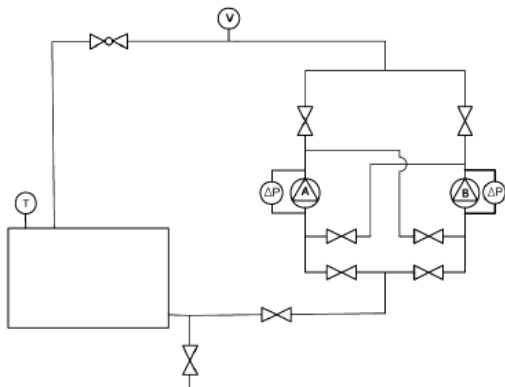
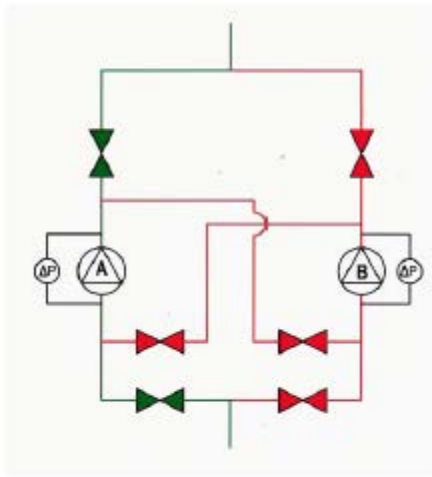


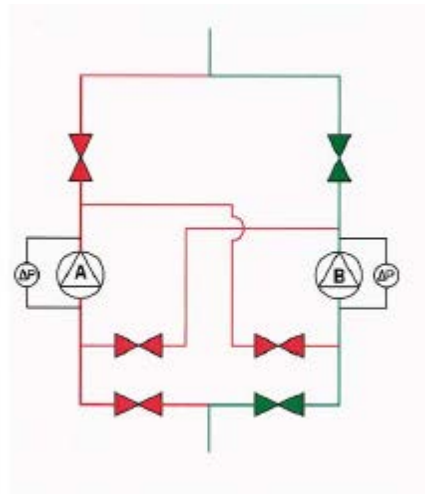
Figure 1. Flow diagram of the apparatus and photo of the apparatus.

On the right hand side of the control panel is located the central switch to start the whole apparatus. Pumps are then switched on individually (**2** and **6**) in the lower part of the panel. Frequency of rotation for each pump is set on using a potentiometer next to the corresponding switch of the pump. The frequency is then displayed at the panel of the frequency convertor, along with pump power input in kW. The values of the pressure difference (in kPa) are then read at the control panel (positions **5.1** and **9.1**). The flow rate is displayed directly at the body of the flow meter **10**. The control panel shows also temperature in the storage tank (**12**).

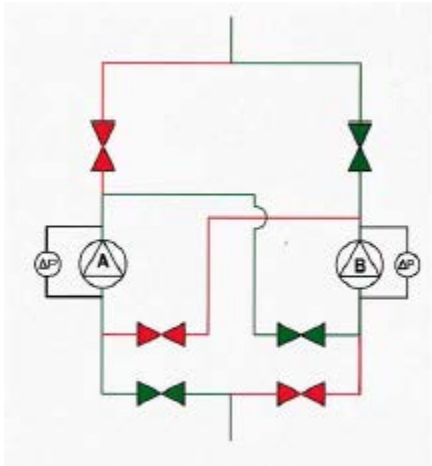
Different options of connecting pumps are schematically documented in Figure 2.



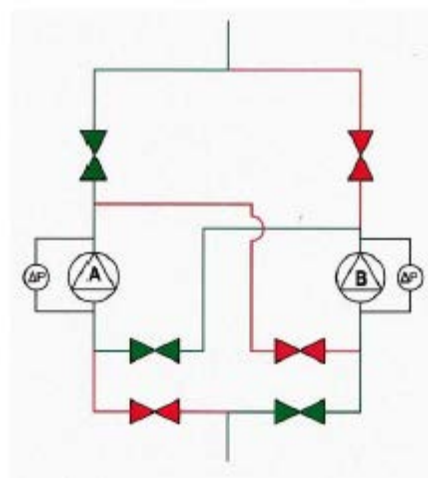
a) Only pump A working



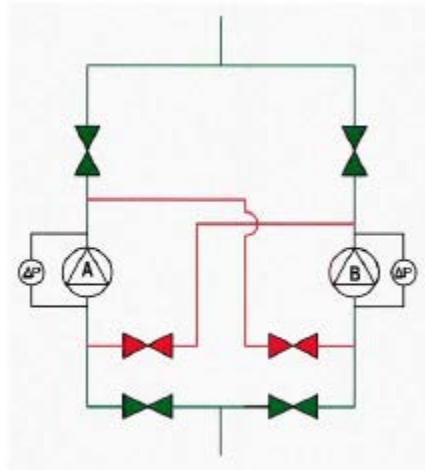
b) Only pump B working



c) Pumps in series A - B



d) Pumps in series B - A



e) Pumps connected in paralel

Figure 2. Schematic guide for connecting pumps of the apparatus. Green: valve is opened; Red: valve is closed.

IV Work procedure

IV.1 Plant preparation

Open ball valves by pumps, to flood both pumps as well as all connections by water. Set the membrane regulating valve into a middle position and switch on the control panel.

IV.2 Measurement

According to the task list, open or close valves using corresponding diagram in fig. 2 to get requested setup. Switch on corresponding pump(s) on the control panel and set the rotation frequency within ± 5 rpm. Check the maximum flow rate by opening the flow regulating membrane valve fully. The minimum flow rate should be higher than $0.2 \text{ dm}^3\text{s}^{-1}$.

In case of parallel setup is going to be used, switch on the first pump and set its frequency while the other pump is switched off. Then switch off the first pump and switch on the second pump and set its frequency while the first pump is switched off. When both pumps are set, switch on both pumps.

Temperature of the liquid has to be recorded at the beginning and at the end of the measurement of the pump characteristic. Split the range between maximum and minimum flow rates on 10 intervals. After approximate setting of the desired flow rate, the flow rate is recorded into the task list along with the pressure difference on the corresponding pump and its power input

V Safety precautions

1. The pumps must not run dry – they have to be flooded with water during the whole experiment.
2. Piping at the inlet or outlet must not be closed, when the pump is switched on.
3. Minimum flow rate through the flow meter is 0.2 L/s . Below this flow rate, the measured values are imprecise.
4. Do not pour tap water to the reservoir, there is distilled water with extra antibacterial additives.
5. Do not press any other buttons on the frequency converter except those mentioned explicitly in this procedure manual. There is a possibility of resetting the instrument and following damage.
6. Before switching on the main switch of the control panel, sufficient liquid level in the storage tank must be verified.

VI Experimental data processing

During experimental data processing please follow definitions and equations described in part I. Protocol has to include in addition to example of calculation as well the graphs. Each graph has to consist appropriate dependence for all rotation speeds, i.e. three graphs – see part II for more details.

VII List of Symbols

d	diameter of the pump impeller	m
g	gravitation constant	9.81 m s^{-2}
e	specific energy	m^2s^{-2}
h	geometric height	m
H	head of the pump	m
\dot{m}	mass flow rate	kg s^{-1}
n	rotation speed of the pump	s^{-1}
N	power output	W
P	power input	W
p	pressure	Pa
v	velocity	m s^{-1}
\dot{V}	volumetric flow	m^3s^{-1}
Π	dimensionless groups	
η	pump efficiency	-
ρ	fluid density	kg m^{-3}

Subscripts

c pump

VIII Questions

1. How does maximal value of the pump efficiency (qualitatively) depend on rotation speed? When does the pump efficiency equal to zero and why?
2. Could be dependence for one rotation speed estimated for the other speeds if yes which equation describes this dependence? Are experimentally obtained dependencies in agreement with dimensionless equations (similarity theory)?
3. What are two conditions for correctly chosen pump in its working point?

