MEASUREMENT OF A CENTRIFUGAL PUMP
„A” Rig

1. Aim of the measurement

The aim of the measurement is to measure the characteristic curves of a single stage centrifugal pump. A centrifugal pump can be characterised by the flow rate ***Q***, head ***H***, input power $\boldsymbol{P_I}$, efficiency η and the revolution number ***n***. During the measurement session the following functions will be determined at two different revolution numbers:

$\boldsymbol{H} = f_1(\boldsymbol{Q})$	Head as the function of the flow rate.
$\boldsymbol{P_I} = f_2(\boldsymbol{Q})$	Input power as the function of the flow rate.
$\eta = f_3(\boldsymbol{Q})$	Efficiency as the function of the flow rate.

2. Description of the measurement rig

In the first figure the sketch of the measurement can be seen. The centrifugal pump (pump-electric motor-frequency drive) ***S*** conveys the water from the suction pipe – connected to a reservoir – back into the reservoir through a standardised orifice flow plate ***MP*** and an adjustable gate valve **T**.

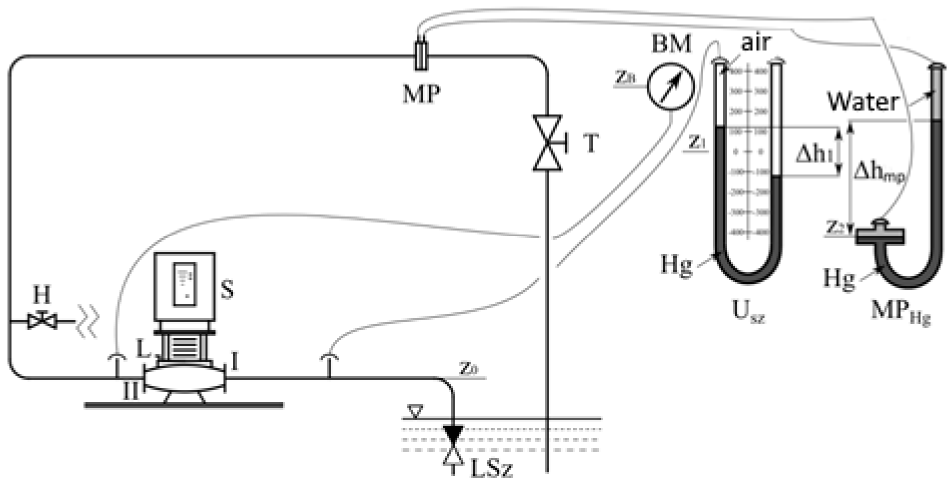

Figure 1. Sketch of the centrifugal pump measurement rig.

Pressure taps are located on both the suction and pressure side to determine the head. The pressure in the pressure side can be measured by a Burdon type $\boldsymbol{B_M}$ manometer directly, while the suction side is connected to a U-type $\boldsymbol{U_{Sz}}$ manometer filled with mercury (the other side is open). Flow rate can be calculated by the pressure difference measured on the orifice flow plate ***MP*** which can be read on the single tube, mercury filled manometer $\boldsymbol{MP_{Hg}}$.

The input power can be monitored on an electric measuring case connected before the frequency drive.

Operation point (flow rate) can be set by the gate valve **T** or by changing the revolution number of the electric motor by the frequency drive.

On the pressure pipe a check valve **LSz** was built in so that after turning of the pump volute could stay under water. Because of the mechanical spring loaded sealing, it is crucial for the operator to check whether the impeller housing is under water before start-up, otherwise the sealing would damage in couple of seconds in a dry operation. For this purpose, a small valve is built in side of the impeller casing, so that before start-up the operator could check if it is filled. When the volute is not filled with water (damage or seepage of the check valve) the suction side and the volute can be refilled by opening a ball valve **H**, connected to the water network.

Figure 2. and 3. Depicts the measurement rig as a whole and its details respectively.

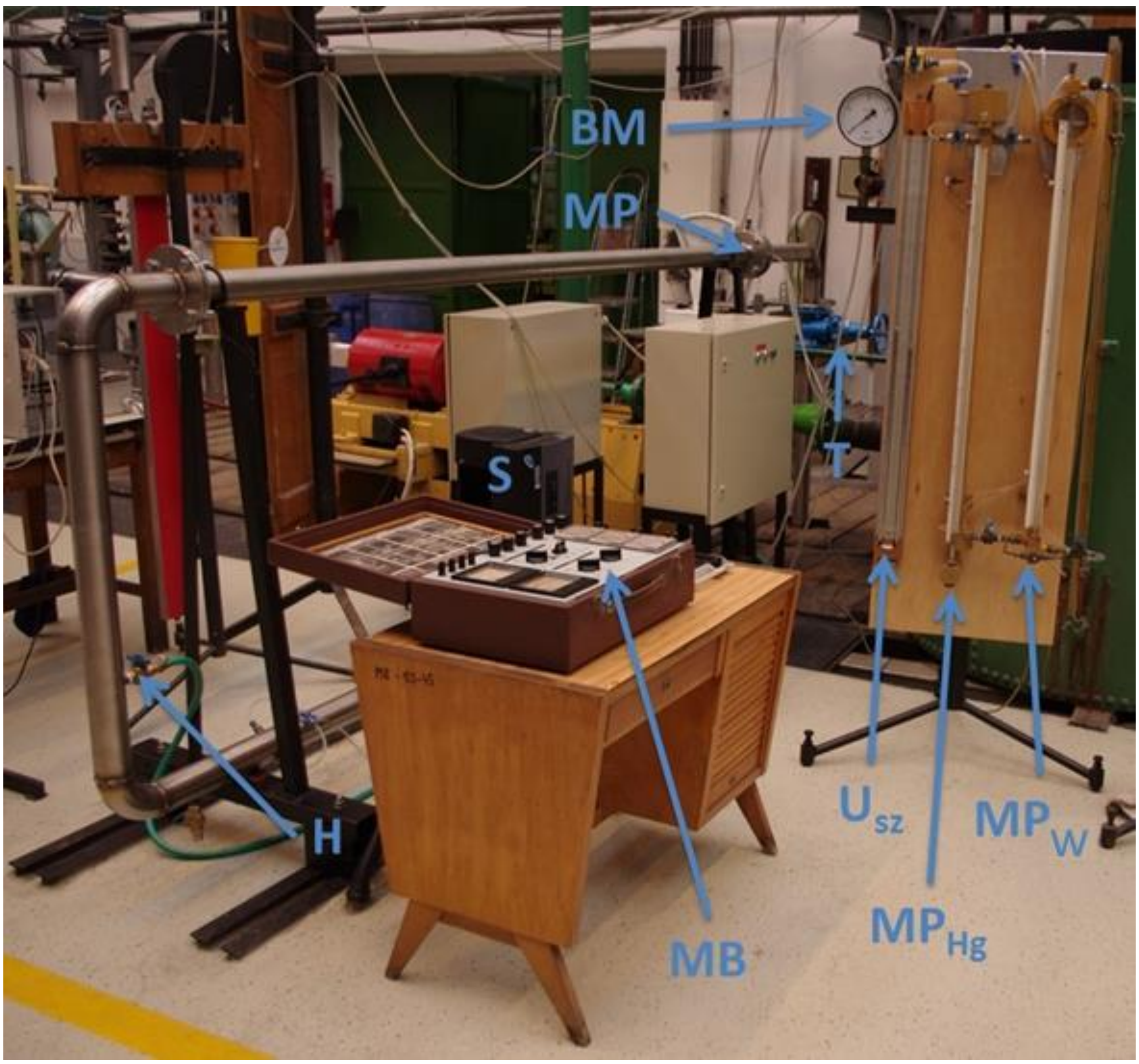

Figure 2. Centrifugal pump „A” rig and its instruments

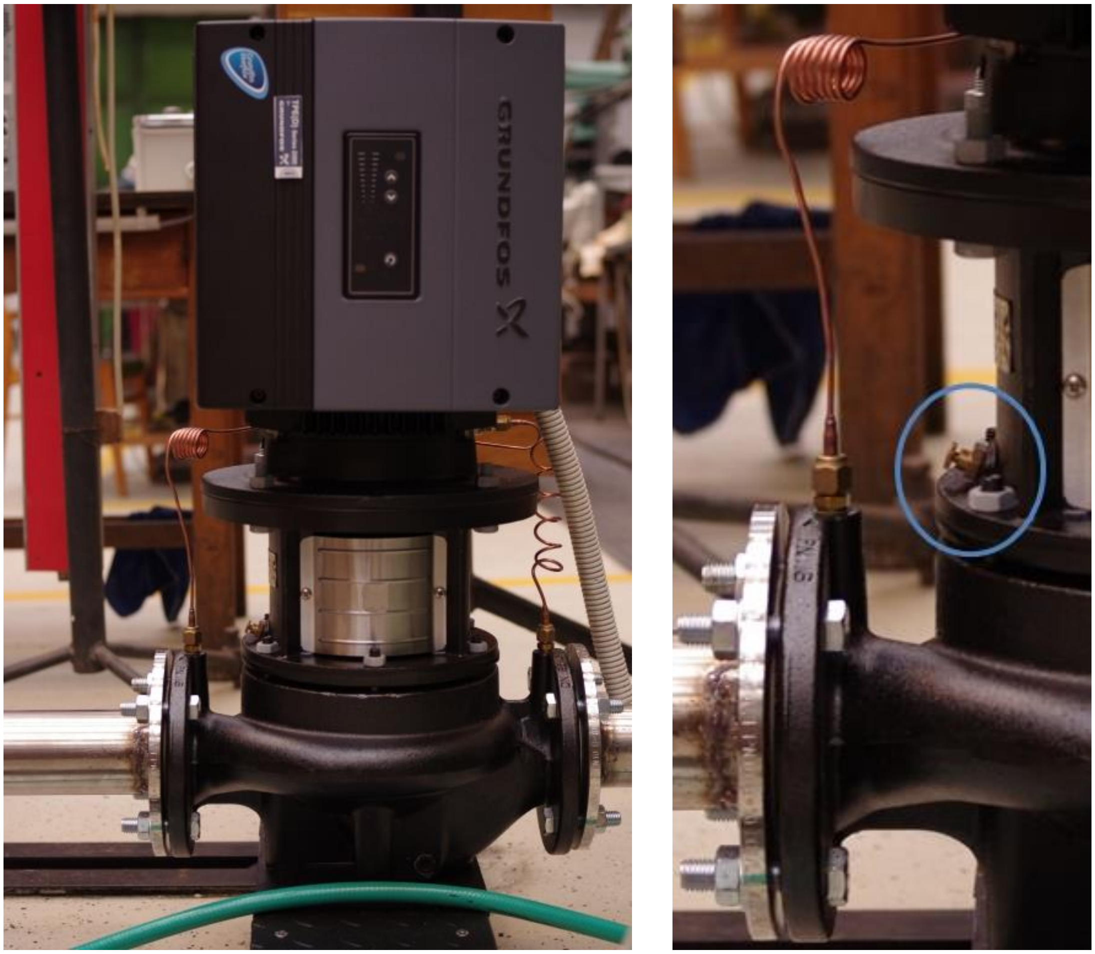

Figure 3. Left: pump-electric motor- frequency drive assembly, right: volute de-air valve.

3. Data of the measuring instruments, material properties

Pipe inner diameter (D)	72 mm
Orifice diameter (d)	52 mm
Name and type of the centrifugal pump assembly	Grundfos TPE 65-340/2
Electric measurement case serial number	4 028 456
Type and serial number of the revolution number measurement device	Voltcraft DT-30LK Serial number.:150706632
Water density under ambient room temperature (ρ_{water})	1000 kg/m^3
Kinematic viscosity of water under ambient room temperature (ν_{water})	10^{-6} m^2/s
Mercury density under ambient room temperature (ρ_M)	13600 kg/m^3

4. Measurement and calculation of the characteristic curve quantities

4.1. Flow rate measurement (Q)

Flow rate measurement is made possible by a standard orifice flow plate. Since this measuring instrument is standardised according to the requirements of the ISO 5167-1 standard, the measurement and the calculation has to satisfy its description. The flow rate Q going through the orifice is proportional with pressure difference Δp_{op} measured between the up- and downstream pressure taps of the device:

$$Q = \alpha \frac{d^2 \pi}{4} \sqrt{\frac{2 \Delta p_{op}}{\rho_{water}}} \quad (1)$$

where:

- d inner diameter of the orifice plate,
- α flow coefficient,
- Δp_{op} pressure difference through the orifice plate.

The formula for the flow coefficient α according to the ISO 5167-1 standard is:

$$\alpha = \frac{C}{\sqrt{1-\beta^4}} \quad (2)$$

Here $\beta = d\,/D$ is the diameter ratio and C is the discharge coefficient. The discharge coefficient could be calculated with the Stolz formula:

$$C = 0{,}5959 + 0{,}0312 \cdot \beta^{2{,}1} - 0{,}184 \cdot \beta^8 + 0{,}0029 \cdot \beta^{2{,}5} \cdot \left(\frac{10^6}{\mathrm{Re}}\right)^{0{,}75} \quad (3)$$

The Re Reynolds number can be computed with c average velocity, the D pipe diameter and the ν kinematic viscosity as follows:

$$\mathrm{Re} = \frac{c \cdot D}{\nu} \quad (4)$$

The flow rate is then calculated in an iteration procedure detailed below.

In the first iteration we assume that the average velocity is $c = 1$ m/s. Then we can calculate the Re number. Using the Re number a discharge coefficient and subsequently the flow coefficient can be approximated. Now the first approximation for the flow rate is given by (1). From the flow rate Q the average velocity c can be obtained. The next iteration step is the same. From the velocity c we can calculate the Re number followed by discharge and the flow coefficient then at last again the flow rate. We iterate the value of the flow rate Q until the relative error between two subsequent flow rate values decrease under 1%.

The pressure difference on the orifice flow plate is measured by a single tube mercury filled manometer. The pressure difference will be calculated as follows:

$$\Delta p_{op} = \Delta h_{op} \cdot (\rho_M - \rho_{water}) \cdot g \ . \qquad (5)$$

4.2. The head (H)

By definition the head is:

$$H = \frac{p_{II} - p_I}{\rho \cdot g} + \frac{c_2^2 - c_1^2}{2 \cdot g} + (h_{II} - h_I) \qquad (6)$$

In equation (6): p is the pressure, c is the average velocity, h is the geodetic level, with index I the suction side, with index II the pressure side was depicted. In the following, the pressure loss between the pumps flanges and pressure measuring taps will be neglected.

p_{II} (gauge pressure) pressure comes from the manometer equilibrium equation for the Bourdon type manometer, where p_{BM} is the value from the Bourdon gauge and the other part is the hydrostatic pressure between the level of the gauge and the level of the pressure taps.

$$p_{II} = p_{BM} + (z_B - z_0) \cdot \rho_{víz} \cdot g \qquad (7)$$

p_I (gauge pressure) pressure comes from the manometer equilibrium equation of the U-tpye manometer (neglecting the density of the air) (notation as in Figure 1.):

$$p_I = -\Delta h_1 \cdot \rho_M \cdot g \qquad (8)$$

Since the suction and pressure pipe have the same diameter and are located on the same geodetic level the head can be calculated by substituting equation (6), (7) and (8) into (9):

$$H = \frac{p_{BM}}{\rho_{víz} \cdot g} + (z_B - z_0) + \Delta h_1 \cdot \frac{\rho_{Hg}}{\rho_{víz}} \qquad (9)$$

During the measurement session the level difference (z_B-z_0) has to be measured on site for the subsequent calculation for the head.

4.3. Input Power (P_I)

In this particular measurement setup, the electrical measurement case directly measures the input power of the whole machine assembly (pump-electric motor-frequency drive). The value read from the device (P_{read}) has to be multiplied with the instruments constant multiplier value (C_w) to get the actual input power:

$$P_I = P_{read} \cdot C_w \qquad (10)$$

4.4. Useful power (P_U)

The useful power of the pump is:

$$P_h = Q \cdot \rho_{víz} \cdot g \cdot H \tag{11}$$

4.5. Efficiency (η)

The efficiency of the whole machine is the ratio of the useful and input power:

$$\eta = \frac{P_h}{P_ö} \tag{12}$$

5. Preparation and operation point setup

The object to be measured is a modern centrifugal pump with an active mechanical sealing system. The advantage of the active spring loaded mechanical sealing system compared to the older gland type sealing system is the better sealing efficiency (no seepage), the zero maintenance and the easy mechanical availability. It has to be remarked though, that in dry operation it can be damaged in second. **Thus, before start-up the operator has to examine that the pump volute is completely filled with water.**

Before the measurement the students:

- Will examine and if needed fill up the pump volute with the ball valve **H**,
- Meanwhile they open the valve located on the side of pump housing to de-air the volute. If the flow is continuous then the valve can be closed.
- Subsequently they close the valve **H** and ask for the teacher to start the machine.
- With the direct help of the teacher they set the revolution number to the desired value for the particular measurement.

The operation points can be set by the gate valve **T**. Then the read out on the instruments (measurement case, manometers) discussed above can be done to measure the quantities. The measured data at each operation points has to be recorded in a table by the student who is responsible for the particular measurement, and then drawn on the verification diagram one by one. **After finishing with the measurement the teacher will shut down the instruments.**

During the measurement the responsible student sketch the $P_{BM}\left(\sqrt{\Delta h_{op}}\right)$ function for verification, as $\sqrt{\Delta h_{op}}$ is proportional with the flow rate *Q* and P_{BM} is proportional with the head *H.*

7. Personal preparation for the measurement

- Learn this description. We will check your knowledge at the beginning of the session.
- Prepare the suitable table on paper or in an excel sheet.
- Bring a mm paper for sketching the verification diagram.

8. Test questions:

- What is the aim of the measurement and what are the quantities that we will measure?
- Sketch and describe the measurement layout!
- Define the flow rate measurement (method, quantities, formula)!
- What is the definition of the head and how can we obtain it? (method, quantities, formula)
- What it the definition of the efficiency?
- List at least four instruments used during the measurement! List the corresponding measured quantity and it unit!
- What are the quantities and their units on the verification diagram?
- What should be examined before starting such pumps and why it is crucial to do so?