MEASUREMENT 6

MEASUREMENT OF PRESSURE LOSSES IN PIPES AND ELBOWS

1. INTRODUCTION

A significant portion of fluid flows occurring in engineering practice is pipe flow. For example, think of a drinking water network, channels, oil and gas pipelines, district heating, or an internal pipeline network for food or chemical plants. The dimensioning of these pipelines is particularly crucial from the hydraulic point of view. Therefore, we need to know the flow loss of pipes and fittings. Based on these, we can select the pump or fan that creates the flow, for example, in a home heating system.

All pipe elements represent flow resistance. The simplest part of the network is the straight pipe section but there are several other elements: bends, elbows, junctions, sudden contractions, valves, etc.

In the case of incompressible fluids - if the pipe cross-section is the same before and after the element - the loss cannot occur in terms of the decrease of the average flow rate, because the continuity equation does not allow this. Therefore, the loss of energy due to resistance occurs in the form of a **pressure drop**. The pressure loss is defined as the difference between the average pressure before and after the tested pipe element. The averaging of the pressure along the cross-section is necessary because the pressure may vary in a cross-section due to different flow asymmetries. In practice, averaging is usually done by linking four pressure taps distributed evenly along the circumference of the pipe. In the current measurement, however, we did not do this averaging because of the small diameter of the pipe.

The pressure drop is given as

$$\Delta p = p_1 - p_2 = \zeta \frac{\rho}{2} v^2 , \qquad (1)$$

where v is the average velocity of the flow, ρ is the constant density of the fluid which is water in our case. Cross-sections „1” and „2” are the locations of the pressure taps of the examined pipe section, ζ is the so-called loss coefficient of the element.

Even in the case of a specific pipe element, ζ depends on several parameters. For instance, the flow velocity, the material properties of the fluid, the roughness of the pipe wall, the geometrical details of the pipe element. A few examples for this are the opening of a valve to varying degrees, the ratio of a sudden cross-sectional change, or the aim of the present measurement: the sharpness of the curvature of the pipe bend (radius of curvature - see Figure 1).

The loss coefficients for the different elements can be obtained from diagrams and tables in the literature, or if the appropriate devices and equipment are available, they can be determined by measurement.

2. AIM OF THE MEASUREMENT

The measurement aims to determine the loss coefficient of a 90° elbow, depending on the volume flow rate and the geometry. The elbow geometry is characterized by the ratio *R/d,* where *R* is the radius of curvature of the centre line and *d* is the inner diameter of the pipe (see Fig. 1). Each of the three measuring groups examines two different curves (thus altogether six). In the evaluation phase of the measurement, the dependence of the resistance of the six elements from the relative radius of curvature is compared. We expect that the loss coefficient increases with a decrease in the radius of the curvature.

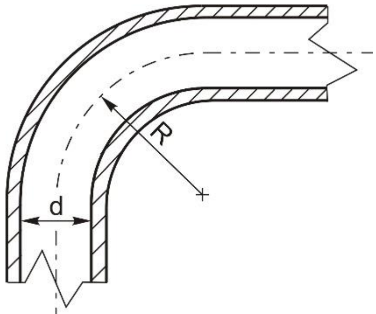

Fig. 1: Inner diameter and radius of curvature of the elbow.

3. THE EXPERIMENTAL SET-UP

The sketch of the measuring device is shown in Figure 2. The WILO centrifugal pump (**P**) conveys the water through the system from the tank (**T**) via a pipe of 20 mm inner diameter. The straight pipes, the examined elbows and the Venturi tube are all in a horizontal plane so that the effect of the gravitation can be ignored. The flow rate is set by the control valve (**V**). The following seven pressure taps are built into the system:

- h_1: the beginning of the straight pipe;
- h_2: the end of the straight pipe and the beginning of the first elbow;
- h_3: the end of the first elbow
- h_4: the beginning of the second elbow;
- h_5: the end of the second elbow;
- h_6 and h_7: the taps of the Venturi tube by d and d_{throat}

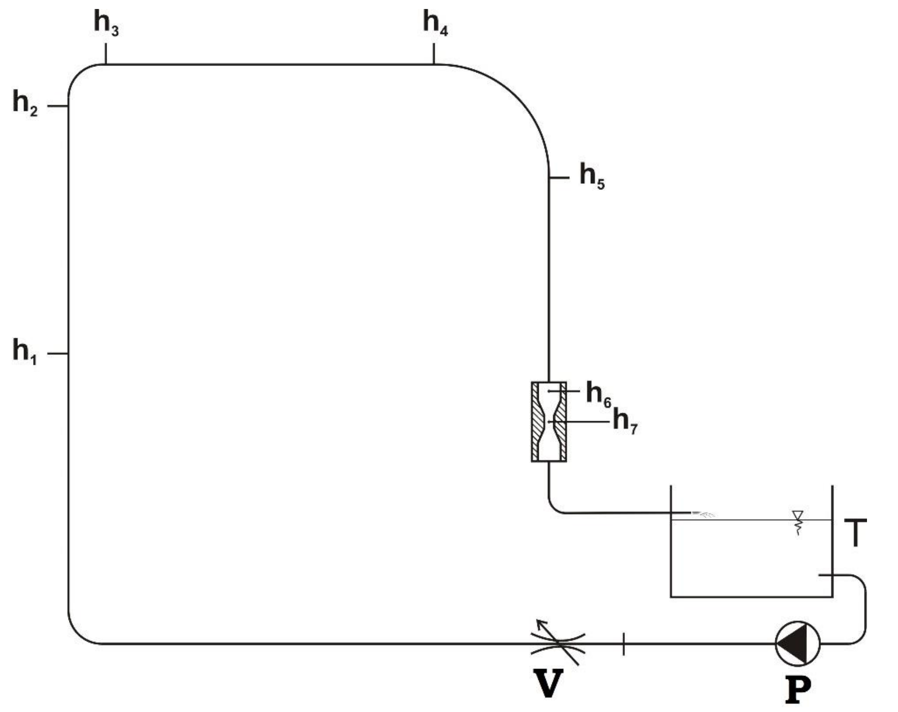

Fig. 2: The sketch of the experimental set-up.

4. Applied devices

During the measurement, we use devices known from the previous laboratory exercises and the lectures. There are several pressure differences that have to be determined. To reduce the number of manometers, the pressure drops are measured by a so-called multi-manometer (Figure 3). The fluid in the multi-manometer is water. The multi-manometer is a set of many one-pipe manometers. The water column height in each branch is proportional to the pressure deviation from a zero level. The zero level can be controlled by adjusting the height of the manometer but in most cases (as in the present one) it has no effect because we are only interested in the pressure differences between the taps and not in the absolute pressure level. (This is typical for the flow of incompressible fluids: the absolute pressure does not play a role, only the pressure differences.)

The locations of the various pressure taps are described in the previous section. The water column levels corresponding to the pressure taps must be read; then, the water column heights and pressure differences can be calculated during the evaluation.

The Venturi tube is used to measure the volume flow rate. The operating principle of the Venturi tube and the corresponding formulae its formula were explained in the lectures.

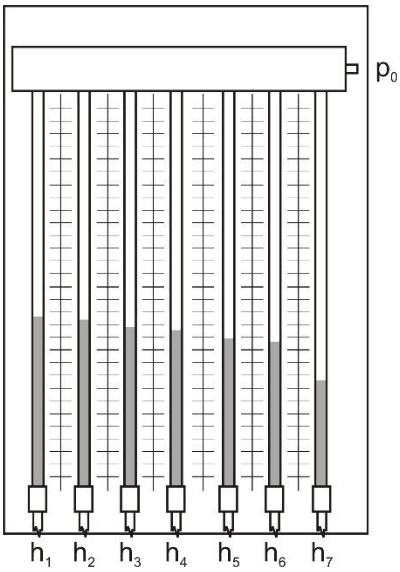

Fig. 3: Multi-manometer

The volume flow rate:

$$Q = k\frac{d_{throat}{}^{2}\pi}{4}\sqrt{\frac{2\Delta p}{\rho\left[1-\left(\frac{d_{throat}}{d}\right)^{4}\right]}}, \tag{2}$$

where d and d_{throat} are the diameters in the two cross-sections where the pressures are measured; that is, the highest diameter before the contraction (d = 20 mm), and the smallest area in the contraction (d_{throat} = 11 mm). The pressure difference between the two pressure taps is Δp, ρ is the density of the fluid (water in our case, ρ = 1000 kg/m^3), and finally, k is a constant that contains the flow losses in the Venturi tube. This is necessary because the losses, though not large, should be taken into account; in our case, k = 0.96.

From the manometer equilibrium, the pressure difference $\Delta p = \rho_{trans} \cdot g \cdot \Delta h$, where ρ_{trans} is the density of the pressure transmission fluid and Δh is the height difference between the two liquid columns. Because both the measurement and the pressure transmission fluid are water, therefore $\rho_{trans} = \rho$.

Substituting this in Formula (2):

$$Q = k\frac{d_{throat}^{2}\pi}{4}\sqrt{\frac{2g\Delta h}{1-\left(\frac{d_{throat}}{d}\right)^{4}}}\,. \tag{3}$$

Note that in (3), all the data are known and constant except Δh; thus, the flow rate can be written as

$$Q = C\sqrt{\Delta h} \tag{4}$$

where C = constant.

5. The measurement

The summary of the measurement and evaluation process step by step is the following:

- Measure the length of the elbow along the centerline (arc) (l) with a measuring tape and calculate the R/d ratio. Watch out: the distance between the pressure taps is not always the same as the length of the curved section. To determine the radius of curvature R, the latter, in formulas (6) and (7), replace the former (l).
- Measure the water column heights from h_1 to h_7 at eight different flow rates. The flow rate is controlled by the throttle valve; the measurements should be carried out in descending order with respect to the flow rates. Do not set very low volumetric flow rates, where the evaluation becomes uncertain: the difference in water column height between the first and last pressure taps should be at least 30 mm.
- Calculate the flow rates based on formula (4), then calculate the average pipe velocities. The unit of the volume flow rate should be in [cm^3/s]!
- Calculate the form loss coefficient for the two elbows and calculate the average loss coefficient using formula (7). For the pipe friction factor λ, the value given below should be used.
- Draw a simple graph based on the measurement leader's instructions, using the average ζ_{form} values of the other groups: plotting the average ζ_{form} as a function of R/d.

Using the formula (5), calculate the pipe friction factor λ based on the first row data. The reference value must be compared to the calculated one.

6. EVALUATION

The pressure loss of the pipe elements consists of two factors: the loss by wall friction and by flow separation because of the form of the elements. Of course, the distinction between these two effects in engineering practice is not clear; nevertheless, this decomposition allows the assessment of the effect of different curvatures on the resistance. Since the lengths of the different elbows are different, the effect of the arc length can be removed by subtracting the friction loss of a straight pipe section of the same length as the arc length from the total friction loss. This way we can compare only the form loss coefficients (ζ_{form}) resulting from the form of the elbow.

To determine the friction factor of an equivalent straight pipe section, we need the pipe friction factor λ. As a simplification, we choose λ = 0.019; however,a straight pipe section built into the system is also used for checking the given value. As part of the evaluation, each student in the measurement calculates λ at a flow rate with the known formula:

$$\lambda = \frac{\Delta p_{12}}{\frac{l_{12}}{d}\frac{\rho}{2}\bar{v}^2}, \tag{5}$$

where Δp_{12} is the pressure difference between the taps of h_1 and h_2, l_{12} is the length of the actual straight pipe section, and d is the inner diameter of the pipe, i.e., 20 mm.

The total pressure loss (Δp) of the elbow consists of the form loss the friction loss of an equivalent straight pipe section calculated from the length (l) and the inner diameter of the elbow:

$$\Delta p = \zeta_{form}\frac{\rho}{2}\bar{v}^2 + \lambda\frac{l}{d}\frac{\rho}{2}\bar{v}^2, \tag{6}$$

and after rearrangement:

$$\zeta_{form} = \frac{\Delta p}{\frac{\rho}{2}\bar{v}^2} - \lambda\frac{l}{d} \ . \tag{7}$$

7. Preparation for the laboratory measurement

- Study the parts of the lecture and problem-solving seminar in the field of hydrodynamics. (Pressure measurement, continuity and Bernoulli equation, volumetric flow rate measurement with Venturi tube, flow losses, etc.)
- Calculate the constant C in equation (4) by replacing Δh in mm and obtaining Q in cm^3/s. The correct C constant is one of the prerequisites for participation in practice.
- Bring one piece of A4 graph paper with you.
- Before the measurement, we shall check the proper preparation for the measurement. The knowledge and the correct use of the formulae used in the measurement through a small numerical example. (For example, sample questions on the website; note: there may be other questions on the "little exam".)
- Fill out the report at home until point 4 (points 5-8 and the table will be taken on the measurement).