Values of the head loss coefficients of elbows in the press system

Wartości współczynników strat miejscowych w kolankach w systemie zaciskowym

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The paper includes values of local head loss coefficients for elbows with pressed ring, which were obtained by direct laboratory measurements, by 3D modelling and analytical calculations using classical energy loss formulas. In the paper, analysis were carried out for three sizes of elbows, the results of which were compared to the values obtained for connectors of corresponding sizes. The obtained values of the coefficients differed significantly depending on the way they were determined. Curves of variation of the loss coefficient values as a function of average velocity were developed based on direct measurements and 3D modelling. These curves are characterized by a non-growing course.
Keywords: elbow, press system, local loss coefficient

Praca zawiera wartości współczynników strat miejscowych dla kolanek systemu wodociągowego z zaprasowywanym pierścieniem, które uzyskano zarówno na drodze bezpośrednich pomiarów w laboratorium, jak i modelowania 3D oraz obliczeń analitycznych z zastosowaniem klasycznych wzorów na straty energii. W pracy przeprowadzono analizy dla trzech rozmiarów kolanek, których wyniki zestawiono z wartościami uzyskanymi dla złączek prostych o odpowiadających im rozmiarach. Uzyskane wartości współczynników różniły się znacząco zależnie od sposobu ich wyznaczenia. Opracowano krzywe zmienności wartości współczynnika strat w funkcji średniej prędkości na bazie pomiarów bezpośrednich i modelowania 3D. Krzywe te cechują się przebiegiem nierosnącym.
Słowa kluczowe: kolanko, system zaciskowy, współczynnik strat miejscowych

Spis symboli

- ζ – local head loss coefficient [-];
- λ – friction factor [-];
- d – elbow internal diameter [mm];
- D – pipeline internal diameter [mm];
- g – acceleration of Gravity [m/s^2]
- h_l – linear head loss [m]
- k – pipe roughness coefficient [m];
- l – linear resistance lenght [m];
- v_d – water velocity in d diameter elbow [m/s]
- v_D – water velocity in D diameter pipeline [m/s]

Introduction

The work is a continuation of the analyzes of the issues undertaken in [10] in the field of minor losses of hydraulic fittings. Among many types of waterpipe systems increasing popularity of plastic systems connected with a pressed steel ring is observed. These systems are characterized by necking of flow active field in a splice. The liquid flowing under pressure in the conduit overcomes the resistance to motion resulting, among others, from changing the layout and geometric parameters (e.g. changing the flow direction), therefore the flow through fittings is more complicated than through straight elements [11], [2], [3]. Over the years many different values of local head loss coefficients for a given type of armature were identified, what from a practical point of view brings difficulties in choosing appropriate design parameters. Currently, there are products available on the market with catalog cards containing the necessary hydraulic characteristics. Presented values of loss coefficients are obligatory used by designers without investigating reliability of this values, what was analyzed in this paper.

In curved conduits under pressure, a pressure difference is created with respect to the inner walls opposite, due to the centrifugal force. The pressure difference cause lateral movement, which along with longitudinal movement cause the formation of a helical movement. This movement is one of the factors influencing the amount of losses. The pressure losses mainly depend on appearance of longitudinal vortex structure immediately following the change of direction. It should be borne in mind that the amount of losses is also influenced by the viscosity of the liquid, which depends on the temperature. Laboratory tests were conducted exclusively for water with a temperature od 13.4°C.

In the paper values of local head loss coefficients for elbows were juxtaposed. These values were determined in the way of:

- Analytical calculations, i.e. using classical one-dimensional equations In the form of Ancony chart (Energy Grade Line and Hydraulic Grade Line);
- 3D modeling;
- Direct laboratory tests

The above values were compared to the values declared by armature manufacturer.

Three typical installation dimensions were analyzed in he paper:

- 16x2,0 with elbow internal diameter d = 6,5 mm

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- 20x2,0 with elbow internal diameter d = 10,5 mm
- 25x2,5 with elbow internal diameter d = 14,5 mm

To determine the radius of the convex arc, the analyzed elbow was cut longitudinally, and then, using a caliper, an approximate internal radius of 2 mm was determined.

Analytical determination of minor head loss coefficient values

The analytical determination of the value of the loss coefficient is understood as the algebraic sum of local losses at individual points of the elbow, respectively it will be the area reduction loss (inlet to the elbow), the length loss, the loss on the change of direction, the length loss and the expansion loss (outlet from the elbow). According to [5], [6], [7] particular minor losses are determined using the following equations:

- Widening (fig. 1a) and area reduction (fig. 1c) loss

$$\zeta_1 = \left(1 - \frac{d^2}{D^2}\right)^2 \qquad (1a)$$

$$\zeta_3 = 0,5\left(1 - \frac{d^2}{D^2}\right)^2 \qquad (1b)$$

- Direction change loss can be descripted using the Weisbach formula [12] (fig. 1b):

$$\zeta_2 = 0,946 \sin^2\frac{\varphi}{2} + 2,05 \sin^4\frac{\varphi}{2} \qquad (1c)$$

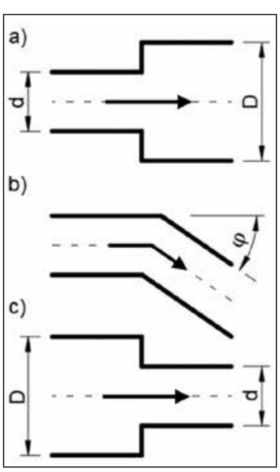


Fig. 1 Schematic of minor loss: a) widening, b) change of direction, c) narrowing
Rys. 1 Schematy oporów miejscowych: a) poszerzenie, b) zmiana kierunku, c) przewężenie

The magnitude of local losses is directly proportional to the square of the mean velocity and is given by a typical formula [4]:

$$h_m = \zeta \frac{v^2}{2g} \qquad (2)$$

It should be borne in mind that using equations (1a) and (1b) in equation (2) the value of velocity behind the analyzed local resistance should be taken.

Although, straight sections occuring in the analyzed elbows are short, the research took into account the occurring friction losses. The applied methodology was described in detail in [10]. According to it linear resistance coefficient is determined using Prandtl-Nikuradse formula [5].

$$\frac{1}{\sqrt{\lambda}} = 2\log\left(\frac{k}{3,71d}\right) \qquad (3)$$

Consider that the scope of application of the Prandtl-Nikuradse formula is limited only to flows with high Reynolds numbers, and its use at low flow velocities ultimately lowers the values of the linear resistance coefficient. Due to the short straight sections (approx. 4 cm of the elbow length), the differences in the friction losses calculated by various formulas for the linear resistance coefficients (e.g. the Zigrang-Silvester formula) will be of little importance from an engineering point of view.

Darcy-Weisbach equation is used for determining the friction losses:

$$h_l = \frac{l}{d}\lambda\frac{v_d^2}{2g} \qquad (4)$$

In the conducted analyzes, the friction losses are presented in the form of a single minor loss coefficient ζ_l, which after appropriate transformations of formulas (3) and (4) takes the form:

$$\zeta_l = \frac{l}{d}\frac{D^4}{d_4}\left[2\log\left(\frac{k}{3,71d}\right)\right]^{-2} \qquad (5)$$

Figure 2 shows Energy Grade Line and Hydraulic Grade Line for the stretched elbow, the diagram of which was used to determine the total minor loss coefficient ζ for an elbow.

After the transformations, the general equation of minor loss coefficient value for an elbow is derived, as marked in the figure 2. The loss coefficient refers to velocity behind the local resistance.

$$\zeta = \left(1 - \frac{d^2}{D^2}\right)^2\left(0,5\frac{D^4}{d^4} + 1\right) + \frac{D^4}{d^4}\left\{0,95\sin^2\frac{\varphi}{2} + 2,05\sin^4\frac{\varphi}{2} + \frac{l}{d}\left[2\log\left(\frac{k}{3,71d}\right)\right]^{-2}\right\} \qquad (6)$$

It should be emphasized that the above formula is based on a simplified method of determining the linear resistance coefficient (Prandtl-Karman formula), where for flows with low Reynolds numbers the values of this coefficient are higher. Minor loss coefficients determined analytically using equation (8) are presented in table 1. The individual values for formula (6) are given in table 1. The k coefficient was accepted, the same as for the pipeline k = 0.007 mm.

Table 1. Head loss coefficients – analytic method
Tabela 1. Wartości współczynników strat miejscowych – metoda analityczna

Size	ζ [-]
16×2.0	15.79
20×2.0	6.76
25×2.5	4.31

As the elbow internal diameter increases, the decrease in loss coefficients values is observed.

Minor loss coefficients declared by the producer

In table 2 coefficients values of analyzed elbows sizes are presented.

Table 2. Head loss coefficients – manufacturer information
Tabela 2. Wartości współczynników strat miejscowych – deklaracja producenta

Size	ζ [-]
16×2.0	3.5
20×2.0	3.0
25×2.5	2.0

As in the analytical method, as the diameters increase, the values of the coefficients decrease, but the order of magnitude is many times smaller than it results from the analytical method.

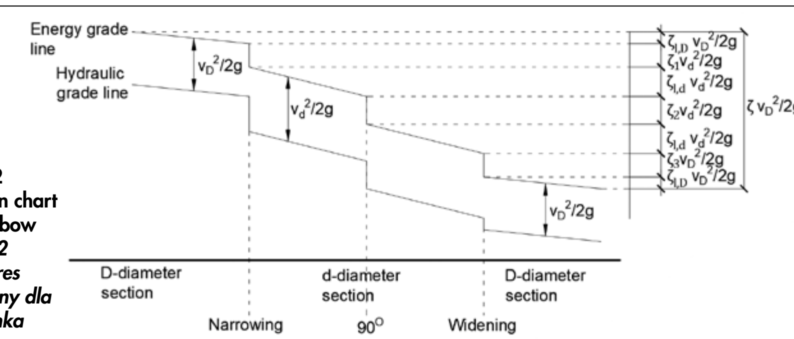


Fig. 2 Ancon chart for elbow
Rys. 2 Wykres Ancony dla kolanka

Determining minor loss coefficient with 3D modelling

Mathematical modeling of three-dimensional flow phenomena is becoming more and more popular due to the increasing computational possibilities. Currently on the market there is a large selection of software for solving Reynolds equation [7]. One of them is the Autodesk CFD used in this paper, which uses the k – ε model to solve the Reynolds equation [8]

The type of minor losses considered in the software apart from elbow flow need to include straight pipe sections, both in front of and behind the elbow, because the velocity distribution need to be aligned at the end of the layout. The analyzes showed that the necessary length of the mentioned sections was 10 cm, and this length was used in the numerical analyzes performed. The difference of inlet and outlet pressure obtained from CFD modelling has to be reduced by friction loss of 20 cm long straight pipe section, which is also obtained by model. The boundary conditions were assumed at the input of the system with velocity values ranging from 0.1 m/s to 2.0 m/s, and at the output of the system, the static pressure equal to 10 mWS (approx. 98 kPa). Obtained in the way of modelling velocity distributions in the layout axis for boundary conditions in the form of steady inlet flow Q = 0,0005 m^3/s and constant inlet velocity v = 2 m/s are shown in the figure 3.

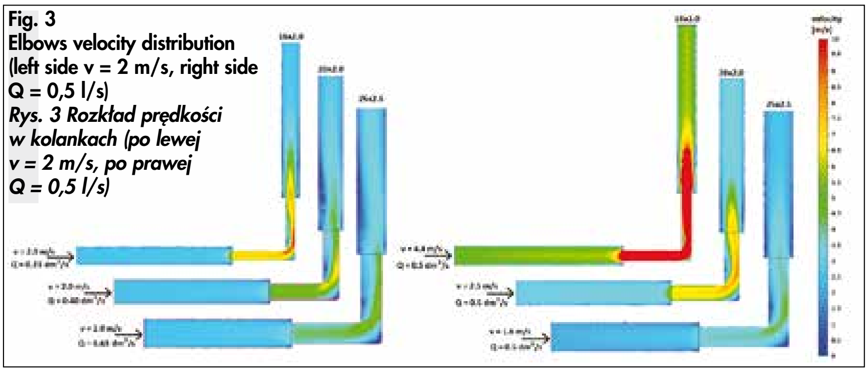


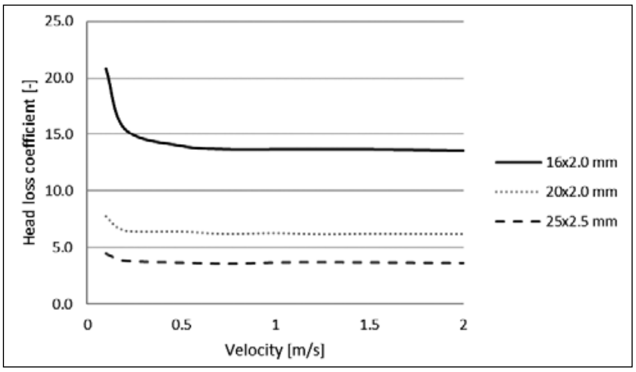
Fig. 3
Elbows velocity distribution (left side v = 2 m/s, right side Q = 0,5 l/s)
Rys. 3 Rozkład prędkości w kolankach (po lewej v = 2 m/s, po prawej Q = 0,5 l/s)

Autodesk CFD uses a 3D mesh of tetrahedra with triangular surfaces. Researches conducted by Kormaz and others [9] showed that the influence of mesh density on obtained straight layouts modelling issues is inconsiderable. It is therefore legitimate to use automatic meshing.

Larger wedge of velocity distribution observed beyond transition from a smaller to a larger cross-section testifies to a calm velocity alignment. The length of this wedge is independent of the size of the elbow.

Variations of coefficient values are presented in the function of mean velocity of water in pipeline, although comprehensive analysis requires presenting curves in a function on Reynolds number. The study did not analyze the pressure losses at different temperatures of the flowing medium, which have a significant impact on the size of the Reynolds number. As designers use mean flow velocities [1] and this paper is of the practical nature, it is justified to present head loss coefficient values against variations of velocity function, as shown in the figure 4.

Fig. 4
Head loss coefficients for elbows – modeling results
Rys. 4 Współczynniki strat miejscowych dla kolanek – wyniki modelowania



The curves of changes in the value of the loss coefficient shown in Figure 4 are of a similar nature, i.e. first the coefficient values drop rapidly with increasing speed, and then, after exceeding the speed of approx. 0.2 m/s, the values of the curves stabilize.

Measuring station

In the tests of pressure losses in the elbows of the clamping system, the measuring stand presented in [3] and [11] was used, the scheme of which is shown in Figure 5. Analyzed moulding is set between impulse hoses (element 5 in the fig. 5), then at a given flow, which amount is read from the ultrasonic flow meter "prosonic Flow 93", a pressure difference is being checked with a EMS-20LR manometer. A detailed description of the measurement is presented in [3]

Determination of minor loss coefficient using direct measurements method

Measurements of values of loss coefficient were carried out on the work station presented in the figure 5. Measurements of pressure losses are performed similarly to the modeling process, i.e. straight 20 cm sections of pipes which are connected to impulse hoses at their ends are mounted on both sides of the analyzed coupling (No. 5 in Figure 6). A pressure difference which is read for a single measure is then reduced by a value read as for a straight 40 cm length pipe section. This procedure provides elimination of energy loss on the height of impulse hoses caused by their connection.

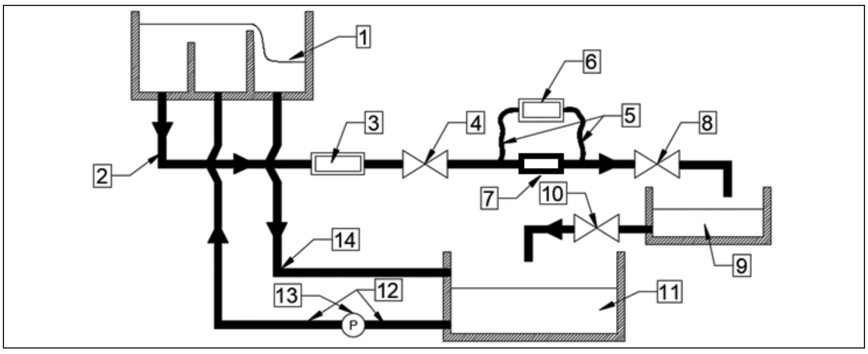


Fig. 5
Work station schematic of head loss determination (1 – upper reservoir, 2 –pipeline, 3 – flow meter, 4 – valve, 5 – impulse wires, 6 – manometer, 7 – elbow, 8 – valve, 9 – control reservoir, 10 – control reservoir valve, 11 – lower reservoir, 12 – pipeline, 13 – pump)
Rys. 5 Schemat stanowiska do badania oporów miejscowych: 1 – zbiornik górny, 2 – rurociąg główny, 3 – miernik przepływu, 4 – zawór, 5 – węże impulsowe, 6 – manometr, 7 – kolanko, 8 – zawór, 9 – zbiornik kontrolny, 10 – zawór zbiornika kontrolnego, 11 – zbiornik dolny, 12 – rurociąg, 13 – pompa

The pressure losses were determined for 3 pieces of the given armature. A single measurement consisted in measuring the pressure difference in steady flow, starting with very low flows, and then with a ball valve (No. 4 in Figure 5), the capacity was slowly increased until the valve was fully open. For a single measurement layout a least 3 series of measurements were performed, paying attention to getting results for the full range o measurements of mean velocity 0 – 2 m/s. In the case of the smallest diameters, maximum speeds were not achieved due to very high pressure losses on the knee. During the measurements, the water temperature was 13.4 °C and did not change during the measurements.

In the figure 6 charts of changes in the loss coefficient values as a function of velocity

The obtained energy loss coefficients confirm the previous rules of decreasing the value with an increase in the average speed and an increase in diameter. Only in the case of the 16 x2.0 mm size, a significant decrease in the value can be observed in the initial phases of the chart. In the case of 16 x2.0 mm elbow, chart begins with a value of 30 and stabilize finally on the level of 20.

Table 3. Head loss coefficients for connectors and elbows – comparing
Tabela 3. Porównanie wartości współczynników strat ciśnienia złączek i kolanek

Size	Manufacturer value	Analytical value	Modeling value	Measured value
Connectors				
16x2.0 mm	**1.0**	9.1	9.0	7.5
20 x2.0 mm	**0.8**	2.7	3.0	0.9
25 x2.0 mm	0.5	1.1	0.9	**0.3**
Elbows				
16 x2.0 mm	**3.5**	15.8	13.6	20.2
20 x2.0 mm	**3.0**	6.8	6.2	5.9
25 x2.0 mm	**2.0**	4.3	3.7	3.5

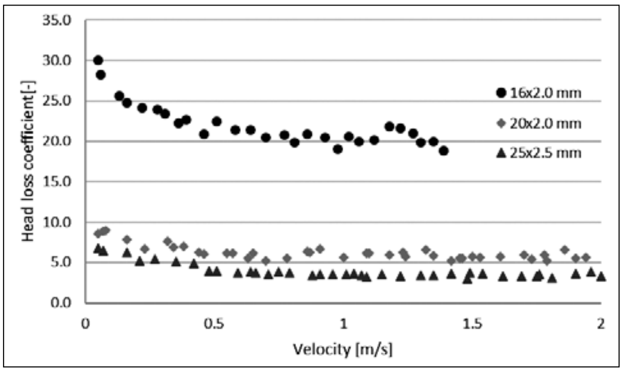


Fig. 6
Head loss coefficients for elbows – measurements results
Rys. 6 Współczynniki strat miejscowych dla kolanek – wyniki pomiarów

Comparative analysis

Due to the practical application of the loss coefficients obtained by numerical modeling and direct measurements, the loss coefficients have been reduced to constant values, what is justified because after exceeding certain velocities the gradient of changes is close to zero. Table 3 summarizes all the values of the coefficients obtained for the elbows. For comparison loss coefficients values obtained for connectors published in [11] are also presented in table

The greatest convergence of results is observed between the values of the coefficients obtained from modeling and the analytical values. This means that there is practical justification for simplifying models to one-dimensional forms.

The lowest values in each category are marked in bold in the table. Among the presented results, in most cases the lowest values of the loss coefficients are given by the manufacturer, except for the measured coefficient for the 25 × 2.5 mm connector.

As is known, the values of the loss coefficients for elbows are greater than for connectors (sometimes even 10 times).

Conclusions

Taking into account in the calculations values significantly deviating from the actual values may result in an increase or decrease of the refrigerant flow.

The work focuses on the determination of pressure losses in elbows used in press systems, in order to deepen and compare the issues discussed in other publications and professional literature. Loss coefficients analysis was a comparison of values declared by a manufacturer, values resulting from the norm [4], values resulting from the3D modeling and direct laboratory measurements. Research has shown that the value of the loss coefficients is mostly influenced by the geometrical parameters of the couplings – the values of the coefficients decrease as the geometrical sizes increase. In the case of the smallest diameter, the coefficients provided by the manufacturer are several times smaller than the values obtained with other methods. As the sizes increase disproportions decreases and it can be expected that for larger diameter sizes coefficients values may be close. In most cases, the lowest values of the loss coefficients are observed in the manufacturer's data, which indicates the need for comprehensive research taking into account, among others, influence of inlet pressure on the value of the loss coefficients, which is ignored in the design guidelines. Due to the very high values of the minor loss coefficient, the pipes of the smallest diameters should be used in low flow rates installation type. As part of further research on the issues of pressure losses, it is necessary to check the effect of changes in the inlet pressure while maintaining a constant flow in the system on changes in the value of the loss coefficient. The presented results can be used by system designers as a source of design parameters. Reducing the flux may result in the design parameters not being achieved. Redesigning the installation means exceeding the design values that arise from the assumption, inter alia, of excessively large wire diameters, ultimately resulting in higher material costs.

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