

DETERMINATION OF LOSS COEFFICIENT IN SELECTED ELEMENTS OF RADIAL FAN

SUMMARY

The article presents a method of measurement and calculation of pressure losses and loss coefficients for inlet cone and inlet chamber of the rotor. Cone coefficients and a total coefficient for a set of elements supplying the radial fan rim are presented and may constitute the base for calculating losses in similar rotors.

Keywords: loss coefficient, inlet cone, axial-radial chamber inlet

WYZNACZANIE WSPÓŁCZYNNIKA STRAT W WYBRANYCH ELEMENTACH WENTYLATORA PROMIENIOWEGO

W artykule przedstawiono sposób pomiaru i obliczeń strat ciśnienia oraz współczynników strat ciśnienia dla leja wlotowego i komory wlotowej wirnika. Podano współczynniki: leja i sumaryczny zestawu elementów zasilających wieniec wirnika promieniowego. Można na ich podstawie obliczać straty w podobnych wirnikach.

Słowa kluczowe: współczynniki strat ciśnienia, lej wlotowy, osiowo-promieniowa komora wlotowa wirnika

1. INTRODUCTION

Losses in elements which are located between the measurement section at the fan suction and inlet section to the rotor rim should be calculated in order to make analytical calculation of useful whirl work. Elements located between these section in the following order are: straight connection pipe, inlet cone, and rotor inlet chamber. It is easy to calculate friction loss in straight connection part on the basis of available literature. However, there are no reliable data for calculation of losses in the cone and the rotor inlet chamber. The author performed suitable flow tests which became the basis for determining loss coefficients of independently working cone and the set of cone-inlet chamber. Positioning of these two elements in their natural system of operation in the fan and supplying them with air stream allowed determination of loss coefficient for the set when both elements were motionless. The experiment corresponding to the rotor

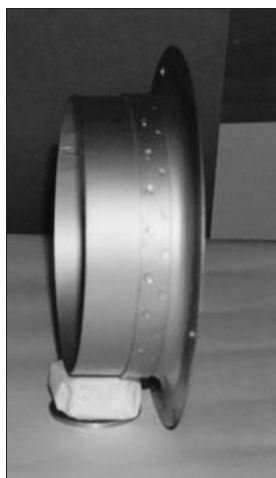


Fig. 1. Inlet cone

work. This test was particularly interesting because its results may be directly applied to calculation of total loss in the fan stage.

2. DETERMINATION OF INLET CONE LOSS COEFFICIENT

The tested cone is presented in Figure 1, and dimensions of the cone are shown in Figure 2.

Measurement diagram for determination of inlet cone losses is presented in Figure 3. The cone was installed at the end of the measurement pipe with orifice ISA D220/d155, PN-93/M-53950/01. Section "1-1" marked before the cone served for measurement of overpressure, velocity c_1 was determined with equation of continuity. Length of straight connection pipes was suitable for correct measurement of static pressure and differential pressure at the orifice.

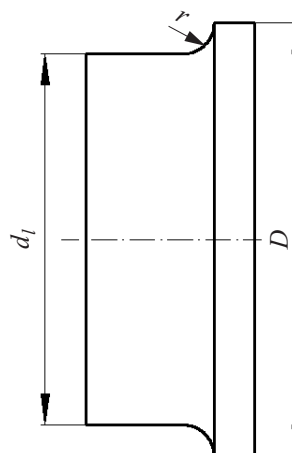


Fig. 2. Cone dimensions: $d_1 = 203$ mm,
 $D = 220$ mm, $r = 15$ mm

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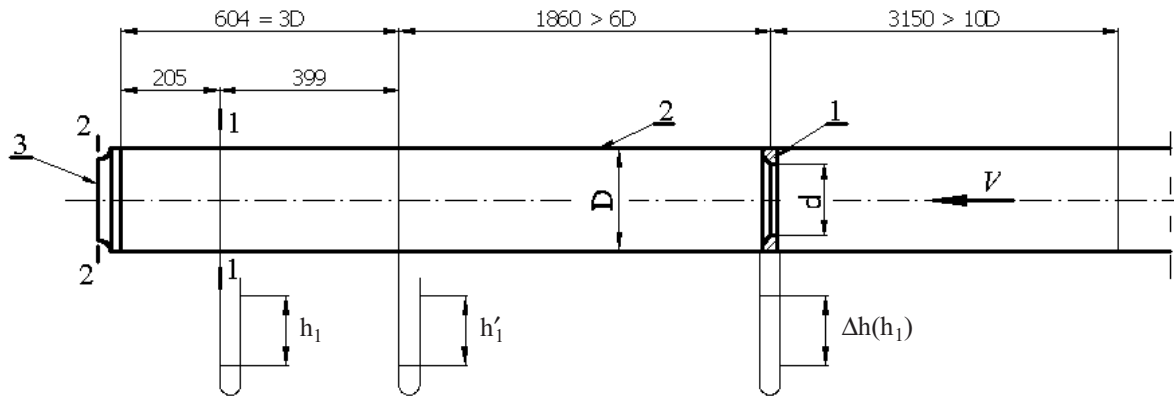


Fig. 3. Measurement diagram for determination of losses in the inlet cone. 1 – measurement orifice ISA D 220 / d155, 2 – measurement pipeline, 3 – inlet cone

A blowing fan supplied air stream V , h_1 i h'_1 were measured in order to check whether pressures behind the orifice were equalized. It was found that pressure measurement at h_1 point was correct.

RESULTS OF MEASUREMENTS

Measurement constant parameters:

- barometric pressure $p_b = 99\,190$ Pa,
- relative air humidity $\varphi = 67\%$,
- ambient temperature $t_1 = 14^\circ\text{C}$,
- pressure of saturated steam at this temperature $p_p'' = 1597$ Pa,
- steam density $\rho_p'' = 0.0113$ kg/m³,
- air viscosity $\nu = 15.18 \cdot 10^{-6}$ m²/s,
- initial Reynold's value $Re_D = 3 \cdot 10^5$,
- orifice throat $\beta = \frac{155}{220} = 0.70$,
- $\kappa = 1.4$,
- conventional thermal parameters:
 $\rho_N = 1.277$ kg/m³,
 $T_N = 273$ K,
 $p_N = 10^5$ Pa,
- temperature before the reducer $T_1 = T_N + t_1 = 273 + 14 = 287$ K,
- manometric fluid density $\rho_{alk.} = 825$ kg/m³.

Results of measurements for supply streams are shown in Table 1.

Calculation of values necessary for determination of pressure loss coefficient.

Calculation of average air density before the orifice:

$$h_{lsr} = \frac{h_1 + \dots + h_5}{5} = \frac{139 + 313 + 98 + 96 + 54}{5} = 103.6 \text{ mm},$$

$$p = 99190 + 825 \cdot 9.81 \cdot 0.1036 = 100\,018 \text{ Pa},$$

$$\rho = 1.277 \cdot \frac{(100018.5 - 0.68 \cdot 1597) \cdot 273}{10^5 \cdot 287} + 0.67 \cdot 0.0113 = 1.2093 \text{ kg/m}^3.$$

Calculation of constant K :

Formulas contained in standard [5] are applied in calculations:

$$C = 0.5959 + 0.031 \cdot 0.7^{2.1} - 0.184 \cdot 0.7^8 + 0.0029 \cdot 0.7^{2.5} \cdot \left(\frac{10^6}{3 \cdot 10^5} \right)^{0.75} = 0.6029,$$

Table 1. Flow parameters for variable cone supplying streams

Description	Unit	Measurement				
		1	2	3	4	5
Overpressure height before the orifice (h_1)	mm alcohol	139	131	98	96	54
Differential pressure height Δh	mm	222	212	160	153	86
Overpressure height h_1	mm	11,5	10	7	7	4
Overpressure height h'_1	mm	11,5	10	7	7	4

$$\Delta h_{sr} = \frac{\Delta h_1 + \dots + \Delta h_5}{5} = \frac{222 + 212 + 160 + 153 + 86}{5} = 166.6 \text{ mm},$$

$$\Delta p_{sr} = 825 \cdot 9.81 \cdot 0.1666 = 1348.3 \text{ Pa},$$

$$\varepsilon_1 = 1 - (0.41 + 0.35 \cdot 0.7^4) \cdot \frac{1348.3}{1.4 \cdot 100018.5} = 0.9952,$$

$$K = \frac{0.6029}{\sqrt{1-0.7^4}} \cdot 0.9952 \cdot \frac{3.14 \cdot 0.155^2}{4} \cdot \frac{\sqrt{825 \cdot 9.81 \cdot 10^{-3}}}{\sqrt{1.2093}} \cdot \sqrt{2} = 0.04749 \text{ m}^{2.5}/\text{s}.$$

Calculation of capacity $\dot{V}_1$ and air density ρ_1 at the cone inlet:

- calculations for measurement 1 – according to the formula for differential pressure

$$\Delta p = 0.222 \cdot 825 \cdot 9.81 = 1796.7 \text{ Pa},$$

- according to the formula for overpressure in section “1-1” of the pipeline

$$p_1 = 99190 + 0.0115 \cdot 825 \cdot 9.81 = 99283.1 \text{ Pa},$$

- according to the formula for overpressure in the pipeline before the orifice

$$p = 99190 + 0.139 \cdot 9.81 \cdot 825 = 100315 \text{ Pa},$$

- according to formula $\dot{V} = k\sqrt{\Delta h}$

$$\dot{V} = 0.04749 \cdot \sqrt{222} = 0.7076 \text{ m}^3/\text{s},$$

- according to formula $\dot{V}_1 = \dot{V} \cdot \frac{p}{p_1}$

$$\dot{V}_1 = 0.7076 \cdot \frac{100315}{99283} = 0.7149 \text{ m}^3/\text{s},$$

- according to formula $\rho_1 = \rho \cdot \frac{p_1}{p}$

$$\rho_1 = 1.2093 \cdot \frac{99283}{100315} = 1.1969 \text{ kg/m}^3.$$

Calculations of subsequent measurement points are presented in Table 2.

Calculation of air flow velocity before and behind the cone:

- section area 1 is $A_s = \frac{\pi d_s^2}{4} = 0.038 \text{ m}^2$,

- section area 2 is $A_L = \frac{\pi d_L^2}{4} = 0.033 \text{ m}^2$.

Velocities are shown in Table 3.

Table 2. Results of calculations of capacity and density in the inlet section to the cone

Description	Unit	Measurement				
		1	2	3	4	5
Differential pressure Δp	Pa	1796.1	1715.8	1294.9	1238.3	696.0
Capacity at orifice $\dot{V}$	m ³ /s	0.7076	0.6915	0.6007	0.5874	0.4404
Capacity before cone $\dot{V}_1$	m ³ /s	0.7149	0.6983	0.6051	0.5917	0.4422
Pressure p_1	Pa	99 283	99 271	99 247	99 247	99 222
Pressure p before orifice	Pa	100 315	100 250	99 983	99 967	99 627
Air density ρ_1	kg/m ³	1.1969	1.1975	1.2004	1.2006	1.2044

Table 3. List of results of calculations of flow velocity in sections 1 and 2

Description	Unit	Measurement				
		1	2	3	4	5
Capacity $\dot{V}_1$	m ³ /s	0.7149	0.6983	0.6051	0.5917	0.4427
Velocity c_1	m/s	21.7	21.17	18.35	17.93	13.40
Velocity c_2	m/s	18.83	18.37	15.94	15.57	11.63

Calculation of pressure loss and loss coefficient for the cone.

Losses in the cone for sections 1 and 2 are calculated with Bernoulli equation

$$\frac{\rho_1 \cdot c_2^2}{2} + \Delta P_{str} = \frac{\rho_1 \cdot c_1^2}{2} + h_1 \cdot \rho_{alk} \cdot \rho \quad (1)$$

where $\Delta P_{str} = \Delta p_L + \Delta p_t$ (loss in cone and straight connection pipe).

The result obtained after substitution

$$\Delta p_L = \frac{\rho_1}{2} \cdot (c_1^2 + c_2^2) + h_1 \cdot \rho_{alk} \cdot g - \lambda \frac{l}{D} \cdot \rho_1 \frac{c_1^2}{2} \quad (2)$$

Loss coefficient is calculated according to the formula

$$\xi_L = \frac{2\Delta p_L}{\rho_1 \cdot c_1^2} \quad (3)$$

Calculations for measurement 1 are

$$\begin{aligned} \Delta p_L &= \frac{1.1969(18.83^2 - 21.7^2)}{2} + 0.0115 \cdot 825 \cdot 9.81 - \\ &- 0.015 \cdot \frac{0.2}{0.22} \cdot \frac{1.1969}{2} \cdot 18.83^2 = 19.5 \text{ Pa}, \end{aligned}$$

where:

$$\lambda = 0.015,$$

$$l = 0.200 \text{ m} - \text{length of straight connection pipe},$$

$$D = 0.220 \text{ m},$$

$$\text{Re} = \frac{d_s \cdot c_s}{\nu} = \frac{0.22 \cdot 18.83}{15.68} \cdot 10^6 = 264196,$$

$$\lambda = 0.0072 + \frac{0.61}{79.0} = 0.0072 + 0.007 \approx 0.015.$$

Results are shown in Table 4.

Losses in the straight connection pipe are easy to determine theoretically with friction coefficient λ .

Comparison of the result with standard values according to PN-76/M-34034 [2] (Tab. 5).

$$r = 15 \text{ mm},$$

$$d = d_L = 203 \text{ mm},$$

$$D = 220 \text{ mm},$$

$\xi_L = f\left(\frac{r}{d}\right) = Z = 0.19$ for straight inlet rounded in the wall – No. 1 standard [2] (Fig. 4).

$\xi_L = Z \cdot \left(1 - \frac{d^2}{D^2}\right) = 0.18 \cdot 0.13 = 0.023$ – for a rounded reducer No. 8 standard [2] (Fig. 5).

Table 4. List of calculated losses and pressure loss coefficient in the cone

Description	Unit	Measurement				
		1	2	3	4	5
Overpressure before the cone h_1	mm alc.	11.5	10	7	7	4
Air density ρ_1	kg/m ³	1.1969	1.1975	1.2004	1.2006	1.2044
Pressure loss at cone Δp_L	Pa	19.5	13.0	4.7	5.8	4.3
Loss coefficient ξ_L	Pa	0.069	0.048	0.023	0.030	0.040
Average coefficient	–	0.42				

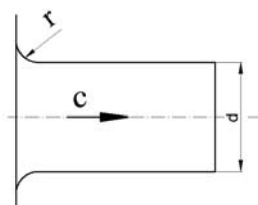


Fig. 4. Straight inlet

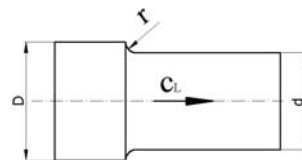


Fig. 5. Rounded reducer

Table 5

Loss coefficient	Own experiment	PN-76/M-34034	
		Inlet No. 1	Reducer No. 8
ξ_L	0.042	0.190	0.023

3. DETERMINATION OF PRESSURE LOSS AND LOSS COEFFICIENT IN ROTOR INLET CHAMBER

The rotor inlet chamber plays an important role in rotor operation. Losses occurring in the chamber result from changing axial direction of the flow to the radial one, missing of main stream with slot stream, and losses of flow delay originated in the increase of inlet circular section area in relation to the cylindrical section at the outlet. The inlet chamber is presented in Figure 6.

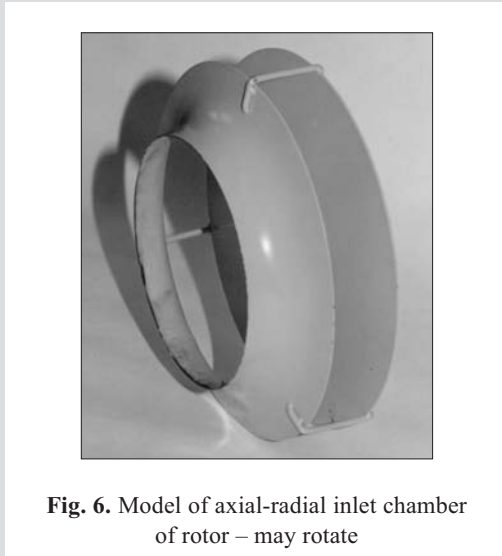


Fig. 6. Model of axial-radial inlet chamber of rotor – may rotate

Literature does not provide information on losses occurring in this important flow element of radial machines. Polish Standard [2] provides loss coefficients for the rounded pipe outlet and blow-out to the screen. Due to geometric similarity with the rotor inlet chamber, these coefficients

may be treated as the basis for selection of loss coefficients for the rotor. Figure 7 shows coefficients which allow to select ξ coefficient = 0.82 for geometrical dimensions of our inlet chamber $\frac{H}{d} = 0.35$ i $\frac{r}{d} = 0.2$.

It seems however, that the selected coefficient may prove incorrect due to rotary motion of the inlet chamber and mixing of slot leakage with main leakage in the machine. That is why, the experiment has been planned to assess value of losses in the rotor inlet chamber. The experiment consists in measuring pressure losses resulted from $\dot{V}$ stream flow through the set of "a" – inlet cone, "b" – inlet chamber, and "c" – pipe (Fig. 8).

Stream $\dot{V}$ was measured with orifice ISA D 220/d155. Pressure loss was measured between circular sections 1-1 and cylindrical section 2-2.

Results of measurements are shown in Tables 6 and 7.

Pressure losses determined according to the formula: where:

$$\begin{aligned}\Delta P_{str} &= P_2 - P_1 + \Delta P_{dyn} = \\ &= P_b - P_b + h_1 \cdot \rho_{cm} \cdot \rho + \frac{1}{2} \rho_{sr} \cdot \dot{V}^2 \left(\frac{1}{A_2^2} - \frac{1}{A_1^2} \right) = \\ &= h_1 \cdot 8,09 - \frac{1}{2} \rho_{sr} \left(\frac{1}{A_2^2} - \frac{1}{A_1^2} \right) \dot{V}^2\end{aligned}\quad (4)$$

where:

$$A_2 = \pi D_2 \cdot b_2 = \pi \cdot 0.225 \cdot 0.075 = 0.053 \text{ m}^2,$$

$$A_1 = \frac{\pi D^2}{4} = \frac{\pi \cdot 0.220^2}{4} = 0.038 \text{ m}^2,$$

ΔP_{dyn} – increase of dynamic pressure.

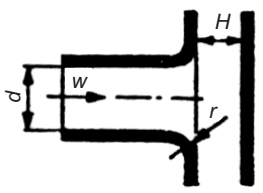
	ξ								
	$\frac{H}{d}$								
	$\frac{r}{d}$								
Outlet rounded to the screen	0.2	0.05	0.07	0.1	0.15	0.2	0.25	0.3	0.35
		–	2.3	0.9	0.52	0.51	0.62	0.75	0.82

Fig. 7. Loss coefficients of rounded outlet [2]

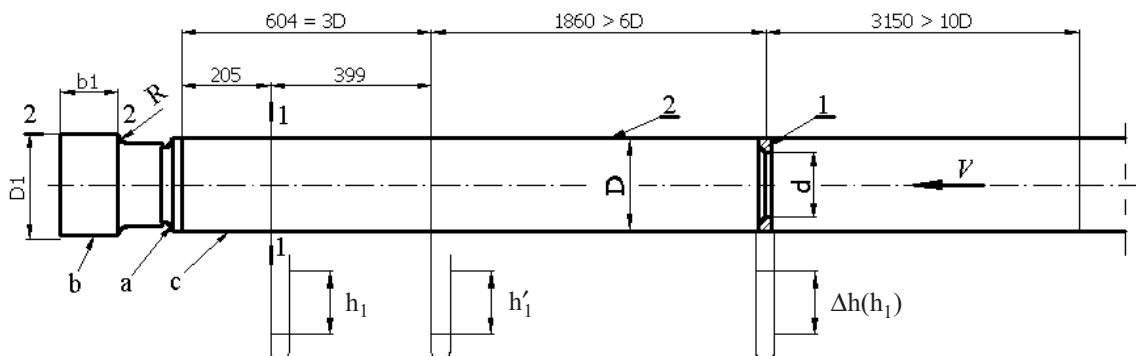


Fig. 8. Stand for measuring losses in the rotor inlet chamber

Table 6. Results of measurements of pressure losses loss coefficients in the set: chamber-cone- pipe; motionless chamber

It.	h_1	Δh	$\dot{V}$	P_1	P_d	ΔP_{str}	ξ	ξ_{sr}
	mm	alc.	m ³ /s	Pa	Pa	Pa	—	
1	44	202	0.690	356	94	450	2.28	2.24
2	28	128	0.550	226	69	295	2.34	
3	18	75	0.420	146	35	181	2.47	
4	21	96	0.475	170	45	215	2.29	
5	3	20	0.216	24	10	25	1.75	
6	45	200	0.684	364	93	457	2.35	

Table 7. Results of measurements of pressure losses loss coefficients in the set: chamber-cone- pipe; rotating inlet chamber

It.	h_1	Δh	$\dot{V}$	P_1	P_d	ΔP_{str}	ξ	ξ_{sr}
	mm	alc.	m ³ /s	Pa	Pa	Pa	—	—
1	32	216	0.71	259	100	359	1.71	1.71
2	15	136	0.564	121	63	184	1.39	
3	4	22	0.227	32	−10	22	1.96	
4	33	213	0.706	267	−99	366	1.76	

Loss coefficient calculated according to the formula

$$\xi = \frac{2\Delta P_{str}}{\rho \cdot c_1^2} \quad (5)$$

where:

P_2, P_1 – static pressure in sections 1 and 2
 c_1 – velocity in section A_1 calculated on the basis of filed A_1 and capacity $\dot{V}$.

Other data are available at drawings or in earlier explanations. Loss in straight connection pipe is neglected in equation [3] did not exceed 3 Pa during the experiments.

4. CONCLUSIONS

Loss coefficient for the rotor inlet chamber was determined for the whole system of elements supplying the rotor. Losses in pipe, cone, and inlet chamber should not be treated separately, as the elements are in interaction, so measurement of individual losses would be affected with uncontrolled error. Losses determined for three correlated elements and loss coefficient referred to velocity in section 1 will allow application of the coefficient to calculate losses in geometrically similar radial rotors. Selection of the coefficient based on the available literature does not guarantee

sufficient precision of calculations, because loss coefficient determined for the motionless inlet chamber in author's own experiment is $\xi = 2.24$, and loss coefficient selected according to the Standard (Fig. 7) is only 0.82. In reality, the inlet chamber rotates, so the loss coefficient is smaller than the coefficient determined experimentally for static conditions. As shown in table 7, this coefficient is 1.71.

Individually determined coefficient for the inlet cone is 0.042.

Knowledge of losses is of primary importance in analysis of flow and thermoanemometric measurements, as well as for purposes of analytical determination of useful work. In this view, the determined coefficients, and especially cone-chamber coefficients allow more precise calculations of the loss occurring at the rim supply.

Literature

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