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Investigation of resistance and air leakage of auxiliary ventilation ducting in underground mine in Quang ninh

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Abstract. Ventilation when driving roadways is one of the most important considerations in coal underground mines. Ventilation efficiency depends on fan performance and ventilation ducting system. In recent years in Vietnam, ducts have often been produced domestically. However, parameters of the duct as duct leakage, duct resistance for designing auxiliary ventilation system are referenced from abroad handbook. This lead to inaccurate design results and needs to adjust efficiency of auxiliary ventilation during driving roadways. Determination of duct resistance; air leakage in ducting system have been undertaken. The research result has been used to optimize the auxiliary ventilation system.

Keywords: air leakage, auxiliary ventilation, duct resistance.

INTRODUCTION

The auxiliary ventilation is carried out by bringing air to the work fronts, as the track is advanced, the amount of air that reaches the front gradually decreases due to the greater resistance of the conduit and the increase of the leakage [1]. Complete elimination of air leakage from, or to the duct system is impossible due to the duct quality and numerous joints in the duct system [2].

In Vietnam, studies on an auxiliary ventilation mainly aimed at finding solutions to improve the ventilation efficiency when mining roadways driven in coal mines. The number of these works is not much, especially there is no research on the resistance and air leakage in ducting system being used in coal mines. Up to now, for designing auxiliary ventilation system, duct parameters were referenced from foreign handbook. These data published long time ago, while at present, ducts are made in Vietnam, materials and technology are different from before that affects the optimization of the auxiliary ventilation system.

Therefore, investigation of air leakage and resistance of auxiliary ventilation ducting system in underground mine in Quang ninh has been undertaken. The research result is necessary for optimizing the auxiliary ventilation system.

The parameters of the duct as duct resistance; air leakage play an important role in the design of the auxiliary ventilation.

1. Measurement of duct resistance used in coal underground mines

1. Fundamentals of duct resistance

Air leakage through in ducting system flows in turbulent flow mode [3]. In turbulent flow mode, airflow energy loss for overcoming viscosity of the air due to turbulent vibrations, so this level of energy loss is much higher than that in laminar flow.

Pressure loss due to frictional resistance in a round duct is determined by:

$$\Delta P = H = \lambda * \frac{L}{D} * P_v = 32.25 * \alpha * \frac{L}{D} * \rho * v^2 \quad (1)$$

Where:

ΔP : Pressure loss (head loss) due to frictional resistance in duct L long, mmH₂O;

P_v : Velocity pressure in duct, mmH₂O;

λ : Friction coefficient, dimensionless coefficient;

L: Distance between two cross sections of duct, m;

α : Friction factor for the duct, KgF.s²/m⁴;

D: Diameter of the duct, m;

ρ : Air density, kg/m³;

v: Average velocity at the duct cross-section, m/s.

A relationship between pressure loss and friction factor in duct is given by:

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$$\frac{H}{L} = \frac{P_1 - P_2}{L} = 65.4 * \frac{\alpha}{D} * \frac{\rho * v^2}{2} \quad (2)$$

Where:

P_1 : Pressure of air at section 1;

P_2 : Pressure of air at section 2.

However, at present, there is not expression for calculating friction factor α . It has been determined experimentally.

One of the most basic ventilation equations [4] describes a relationship between pressure loss and airflow volume in a duct is:

$$H = \Delta P = R \cdot Q^2 = R \cdot (v \cdot S)^2 \quad (3)$$

Therefore, friction resistance in ducting system can be obtained by the following equation:

$$R = \frac{H}{v^2 * S^2} \quad (4)$$

Where:

R: Friction resistance, $k\mu$;

S: Cross sections of duct, m^2 .

From equation (4), the specific resistance - r and friction factor of the duct can be found:

$$r = \frac{R}{L} \quad (5)$$

And friction factor α is determined by:

$$\alpha = 0.25 * \frac{H * D}{v^2 * L} \quad (6)$$

2. Experimental Procedures

Laboratory set-up

Experimental model for determination of duct resistance was set up at Institute of Mining Science and Technology - Vinacomin (IMSAT), Uong Bi, Quang Ninh.



Fig.1. Experimental apparatus for determination of duct resistance

Fig.2 shows the schematic diagram for determination of duct resistance.

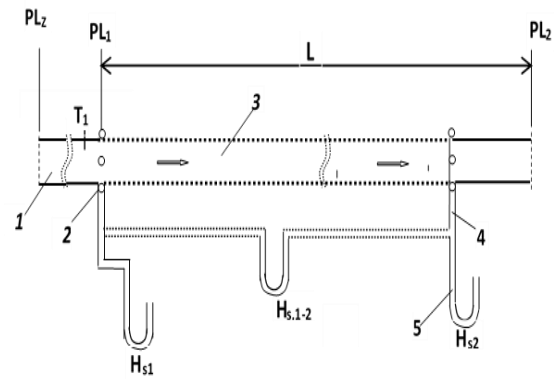


Fig.2. Schematic diagram for determination of duct resistance

- 1- rigid steel ducting; 2- holes for measurement ;
- 3- flexible fabric ducting; 4- pitot -tube; 5- U tube

Fabric duct was connected to the test setup. Fabric duct was connected directly to rigid steel ducting and carried as straight in the horizontal direction. The fan had the capability to blow the airflow into the duct.

According to the authors [5] the process of movement of the airflow in the duct is described by the conservation equation of energy and mass. For determination of duct resistance, assuming that:

- The air flow in the duct is turbulence flow;
- The density of the air is a constant.

Experimental model set up the conditions which must be satisfy the conditions as follows:

- The ducting system must be kept tight, straight during experimental procedures. Hence, the pressure loss on the ductwork was caused by frictional resistance [6]. Since the duct from PL_1 to PL_2 has no joints, local resistance does not appear.

- The test duct length shall be required to arrive at a fully developed turbulent flow [7].

For the model to determine the resistance of the duct with diameter $D = 0.6m$ and air flow $Q = 3.4 m^3 / s$, the velocity in the duct is as:

$$v = 3.4 : \left[\pi * \left(\frac{D}{2} \right)^2 \right] = 12.02 \text{ m/s}$$

Reynolds number:

$$R_e = \frac{v \cdot D}{\nu} = \frac{12.02 * 0.6}{14.4 * 10^{-6}} = 500833$$

Where: ν is the viscosity coefficient of the air, $\nu = 14.4 \times 10^{-6}$

Duct length between two cross sections of duct section must be satisfied:

$$L = 0.639 * R_e^{0.25} * D = 10.2 \text{ (m)}$$

Thus, for the duct with diameter $D = 600\text{mm}$, test duct length is set 15m .

Measurements were conducted on a fabric duct of 600mm diameter, 15m length.

- The system had a fan to supply air flow. The variable speed control unit of the fan was used to obtain a fine adjustment of airflow under $12 \text{ m}^3/\text{s}$.

- Microclimatic conditions during experimental procedures was: temperature 26°C and humidity 62% .

The average velocities in the ducts were obtained using the following method:

Velocity v at the center of each section was measured by a pitot tube. The cross sectional area of the duct was equally divided into four areas, 16 points traverse as shown in Fig.3 [8].

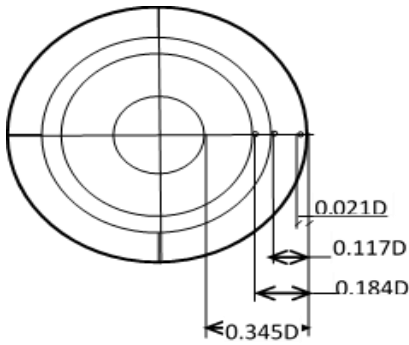


Fig 3. Diagram position of traverse points in a circular measurement section for 4- area, 16 point traverse

The average velocity V in the duct was calculated from the arithmetical mean value of v [9]. From that the average velocities at the measuring of the pressure drops along the ducts can be estimated.

At the same time, the pressure difference between the pressure PL_1 and PL_2 was measured and related with the average velocity V .

Fig.4 shows cross sectional area for the pressure measurement and pitots in practice.



Fig 4. Cross sectional area for pressure measurement and pitots

3. Test Results

Experimental data for determining duct resistance R , specific resistance r and friction factors are shown in Table 1.

Average values of the resistance R , specific resistance r and friction factors calculated for test ducting are as:

$$\bar{R} = 0.4041 \text{ k}\mu; \bar{r} = 0.0269 \text{ k}\mu \cdot \text{m}^{-1};$$

$$\bar{\alpha} = 0.00030 \text{ KgF} \cdot \text{s}^2 \cdot \text{m}^{-4}$$

The values for the measured friction factor is small compare with published values calculated by others as shown in Table 2 [10].

However, the measured friction coefficient ($0.0003 \text{ kgF} \cdot \text{s}^2 / \text{m}^4$) is much smaller with the value using the auxiliary ventilation design in Vietnam ($0.00048 \text{ kgF} \cdot \text{s}^2 / \text{m}^4$). Accurately estimating the friction coefficient is thus crucially important to design auxiliary ventilation in underground mine.

Table 1. Experimental data and results for determining duct resistance

Measurement	1	2	3	4	5
Airflow $Q, \text{ m}^3/\text{s}$	7.33	7.42	7.42	7.42	7.43
Pressure at section $PL_1, \text{ Pa}$	785	784	781	780	777
Pressure at section $PL_2, \text{ Pa}$	558	569	553	564	555
Resistance $R, \text{ k}\mu$	0.4224	0.3902	0.4138	0.3921	0.40201
Specific resistance $r, \text{ k}\mu/\text{m}$	0,02816	0,02602	0,02759	0,02610	0,02680
Friction factor α $\text{KgF} \cdot \text{s}^2/\text{m}^4$	0.00034	0.0031	0.00033	0.0003	0.00032

Therefore, it is necessary to determine the resistance all types of the ducts being used in auxiliary ventilation when mining roadways driven in coal mines, specially, for a duct produced in Viet Nam.

Friction factor depends on the smoothness of the duct material, diameter as well as the tension level of the ducting system [11].

Table 2. Quoted friction factors for flexible duct.

No	Friction Factor, KgF, s ² /m ⁴	Reference
1	0.00054	Telyakovsky and Komarov, 1969
	0.00046- 0.00048	Burtrakov and Ushakov
2	0.00030	Le Roux, 1979
3	0.00037- 0.00046	Hartman and Mutmanski, 1982
4	0.00051	Baret and Wallman, 1983
5	0.00023	Jones and Rodgers, 1983
6	0.00038	Vutukuri V., 1983
7	0.00030	Institute of Mining Science and Technology - Vinacomin , Vietnam

2. Estimation of air leakage of duct used in coal underground mines

When air flow is moved in ducting system, air leakage is always presented. Air leakage is a complicated aerodynamic phenomenon. If there is not air leakage through the duct, the pressure of the fan generated and the air flow throughout the ducting system can be described by a model quite accurately.

Air leakage can be described in the following two physical models [12].

- Discrete – air leakage leaks through joints of ductwork
- Continuous – randomly distributed outlets along the ductwork walls.

Level of air leakage is mainly influenced by the following factors: total length, diameter of the ducting and airflow in the ducting system [13].

Table 3. Experimental data for the duct of 0.6m diameter

Q(m ³ /s) L(m)	2.0	2.3	2.5	2.8	3.0
	100	1.024	1.026	1.027	1.028
200	1.091	1.097	1.102	1.011	1.118
300	1.203	1.214	1.221	1.230	1.238
400	1.323	1.345	1.368	1.378	1.394
500	1.542	1.568	1.590	1.598	1.642
600	1.749	1.776	1.798	1.838	1.889
700	1.976	2.032	2.078	2.133	2.169
800	2.223	2.305	2.362	2.422	2.465
900	2.561	2.642	2.705	2.722	2.830
Q(m ³ /s) L(m)	3.2	3.4	3.5	3.8	4.0
	100	1.030	1.032	1.033	1.035
200	1.112	1.124	1.125	1.131	1.135
300	1.242	1.249	1.252	1.261	1.272
400	1.415	1.425	1.450	1.476	1.488
500	1.666	1.688	1.678	1.798	1.716
600	1.908	1.930	1.946	1.977	1.995
700	2.193	2.218	2.233	2.268	2.296
800	2.507	2.545	2.570	2.623	2.658
900	2.878	2.925	2.948	3.023	3.061

The experimental data are made on 0.6 m diameter ducts over sections of ducts installing towards the working face in actual field conditions in Quang Ninh coal mine as shown in Tab 3.

Currently, in Quang Ninh mines, airflow volume Q_{face} supplying to the face changes from 2 to 8 m^3/s for the duct of $D = 0.6 \div 0.8$ m; sometimes 1.0 m for large cross-section roadway.

When the length of the duct is extended from 100 m to 700, 800 m, air leakage will increase quite markedly.

Leakage sometimes exceeds 25-30% initial flow volume designed over hundreds m ducting length.

A conceptual prediction model has been proposed based on experimental data at Quang Ninh Coal mine [14].

$$p = f(L, Q) \quad (7)$$

Let p, L and Q represent leakage coefficient, duct length and quantity of airflow in the ducting system respectively. It is assumed to express p in the form:

$$\ln(p - 1) = \ln c + b_1 \ln L + b_2 \ln Q \quad (8)$$

Where:

- p: Leakage coefficient;
- L: Duct length, m;
- Q: Quantity of airflow in the ducting system, m^3/s ;
- $\ln c$, b_1 , b_2 , constants.

Each set of data: $\ln(p_i)$, $\ln(L_i)$ and $\ln(Q_i)$ under given data – duct diameter, with $i=1, 2, \dots, n$.

With ducting length L_i , the quantity of airflow in the ducting system Q_i is measured; the air leakage coefficient p_i is calculated as:

$$p_i = \frac{Q_0}{Q_i}$$

Where: Q_0 the quantity of airflow beyond the fan, m^3/s ; Q_i quantity of airflow reaching the end of the ducting length - L_i .

Let y_i , x_{i1} , x_{i2} and b_0 represent $\ln(p_i - 1)$, $\ln L_i$, $\ln Q_i$ and $\ln c$ respectively. Equation above can be rewritten:

$$y_i = b_0 + b_1 x_{i1} + b_2 x_{i2} \quad (9)$$

Least-squares regression is to fit these experimental data that minimizes the sum of squared residuals [15]:

$$\sum_i^n e_i^2 = \sum_{i=1}^n \left(y_i - b_0 - \sum_{j=1}^2 b_j x_{ij} \right)^2 \quad (10)$$

Take derivatives with respect to the model parameters b_0 , b_1 and b_2 set them equal to zero and derive the least-squares normal equations that our parameter estimates b_0 , b_1 and b_2 would have to fulfil.

Normal equations of two independent variables can be written in matrix form as:

$$\begin{pmatrix} \sum_{i=1}^n x_{i1}^2 & \sum_{i=1}^n x_{i1} x_{i2} \\ \sum_{i=1}^n x_{i1} x_{i2} & \sum_{i=1}^n x_{i2}^2 \end{pmatrix} \begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} \sum_{i=1}^n x_{i1} y_i \\ \sum_{i=1}^n x_{i2} y_i \end{pmatrix} \quad (11)$$

Solve the above matrix to obtain the regression coefficients.

Therefore, the air leakage coefficient for the duct of 0.6m diameter can be obtained based on data at Quang Ninh mine:

$$p = 1 + 3.1257 \cdot 10^{-6} \cdot L^{1.906} \cdot Q^{0.5351} \quad (12)$$

Use the F-test can evaluate $\text{Pro}(F) = 0.0000$ with significance level is 0.5. This low a value would imply that the regression parameters are nonzero and the regression equation does have some validity in fitting the data.

CONCLUSION

The resistance and air leakage of the duct depends on many factors, in which the ducting material and size play an important role.

For designing auxiliary ventilation system, duct parameters were referenced from foreign handbook that causes results in lack of confidence.

Factors such as duct size and diameter, aerodynamic parameters in duct airflow influence on duct air leakage.

A conceptual prediction mode can be determined duct air leakage based on the experimental data at Quang Ninh mine.

Also, the research result has been used to optimize the auxiliary ventilation system. Optimization of the auxiliary ventilation system can save cost and energy.

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