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Design process and equipment selection for auxiliary ventilation systems

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ABSTRACT: The design of auxiliary ventilation system(AVS) and optimal equipment selection can be a problem, especially in case of very long drivages and high rock temperature. Algorithms for calculation of AVS parameters are basically developed by use of essential relationships from fluid mechanics. In a leaky duct, in addition to the variation of pressure, the flow rate varies along the duct and calculations are not straightforward. In the paper some of most successful models have been generalized and algorithms for calculations presented. Two basic models of leaking ducts are discussed: 1st model for a duct with leakage through the flange joints; 2nd model for a duct with an equivalent longitudinal aperture. The presented analytical system has been successfully applied to developing a computer program, named DAVentS. A sample problems are used to illustrate the efficiency and accuracy of DAVentS software in solving most common problems in the process of designing AVS and especially in the process of equipment selection.

1 INTRODUCTION

Basic parameters which characterized work of an auxiliary ventilation system(AVS) with one fan mounted on the end of the duct are:

- fan flow rate Q_f [m³/sec],
- quantity of air reaching the end of the duct Q_0 [m³/sec],
- pressure loss W [Pa],
- pressure of fans P_f [Pa] which is equal to the pressure loss W,
- coefficients which characterized the air leakage of the duct η and p, expressed by the following equations;

$$\eta = Q_o/Q_f \tag{1}$$

$$p = Q_f/Q_o = 1/\eta \tag{2}$$

Calculations used in design process of leakless duct are reduced to calculations of static fan pressure with known volume flow through the duct (Q) using the equation:

$$\Delta P_f = 6.5 \frac{\alpha.L}{d^5}.Q^2 = R.Q^2 \tag{3}$$

where; α = friction factor for the duct, [Ns²/m⁴] or [kg/m³]; L = duct length, [m]; d = duct diameter,[m]; R = aerodynamical resistance of the duct,[Ns²/m⁸] or [kg/m⁷].

In a leaky duct, in addition to the variation of pressure, the flow rate varies along the duct and calculations are not straightforward.

A number of calculation methods are published [Voronin, 1951; Pawinski et al., 1979; Browning, 1983; Vutukuri,1984; Calizaya and P. Mouset-Jones, 1993 and others]. Algorithms and formulas derived depend on the model accepted, for both, shape and distribution of the leakage paths along the duct. In the papers [Dimitrov and Kertikov, 1988; Kertikov, 1994; Kertikov, 1996] some of most successful models have been generalized and algorithms for calculations presented. In the next two chapters of this paper short descriptions of the models are presented.

Depending on shape and distribution of the leakage paths along the duct there can be two basic models:

a) model for a duct with leakage through the flange joints;
b) model for a duct with an equivalent longitudinal aperture.

1.1 Model for a duct with leakage through the flange joints

Figure 1 shows a schematic presentation of a duct with this kind of leakage. The duct is composed of separate segments of length l. As a result of duct imperfects assembling there are apertures of width A in the flanges between them, and air flow rates of ΔQ leak through them.
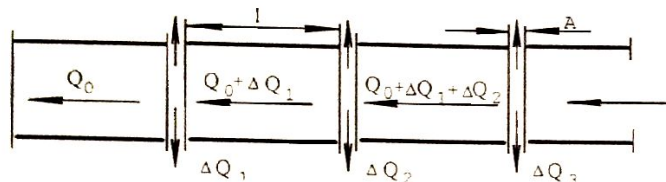
Figure 1. Model for a duct with leakage through the flange joint

Two calculating algorithms for this model are presented below (Dimitrov & Kertikov 1988, Kertikov 1994,1996):
a) algorithm "Ventilation network"
b) algorithm "Leakage paths"

The AVS with a leaky ventilation duct is treated as ventilation network (See Figure 2) composed of simple parallel contours or meshes. There are three types of branches in the network.
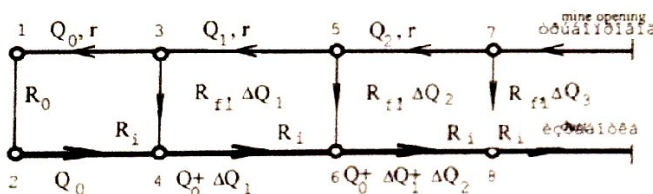
Figure 2. Representing AVS as ventilation network

Type1: Represents duct segments of resistance r, that are connected together using flange joints

Type 2: Represents the apertures of the flange joints with equal resistance R_{fl} [Ns^2/m^8]

Type 3: Represents mine openings of length l and resistance R_0.

A network of this kind can be solved by a computer program, using iterative procedure such as Hardy Cross method. Programs of this type are rather sophisticated. A simpler algorithm has been developed which reduces the complex network to simple parallel networks. The number of these parallel networks, N, is equal to the number of individual duct units (N=L/l).

The first parallel network 3-1,1-2, 2-4 is solved by using followed relationships:

$$R = R_1 / \left(1 + \sqrt{R_1/R_2}\right)^2 \; ; Q = Q_o \tag{4}$$

$$\Delta Q = Q\sqrt{R_1/R_2} \; ; \tag{5}$$

where; $W = R \cdot Q^2$; $R_1 = r + R_O + R_1$ and $R_2 = R_{fl}$.

The next (second) parallel network comprises the first network with total (equivalent) resistance R and branches 5-3,4-6 and 5-6. The left-hand parallel of this mesh (5-3-4-6) has a resistance $R_1 = R + r + R_{fl}$ and volume flow ratio through it is $Q = Q_o = \Delta Q_1$. Right hand paralell branch has a resistance of $R_2 = R_{fl}$. Calculations are repeated until the last N-numbered unit (near the fan) is included in the total ventilation network. The fan operating parameters (Q_f and h_f respectively) are determined by last calcuated values of the rate Q and the loss of pressure P.

In this version of the main model the aperatures of the flange joints are treated as a seqence of leakage paths. The flow rate of the air leaking through an aperature depends on the area of this aperature and the pressure difference between the duct and mine opening P=W. This rate is determined by the following realtionship:

$$\Delta Q = \mu . \pi . d . A \sqrt{2P/\rho} \tag{6}$$

where A is the width of aperture (See Figure 1), and μ is flow coefficient.

Calculations are carried out consecutively for each duct segment from the end of the duct to the fan, and the flow rate Q, the difference between the pressures P, and air losses ΔQ are calculated by using following equations:

$$Q = Q_{(i-1)} + \Delta Q_{(i-1)} \tag{7}$$

$$P = P_{(i-1)} + (r + R_w)Q^2 \tag{8}$$

The last calculated values of Q and P determine the fan operating parameters (Q_f and P_f respectively).

1.2 Model for a duct with equivalent longitudinal aperture

Flange joints are not the only places where air can be leakout of the ducts. Ducts might possess longitudinal cuts and apertures obtained during the installation or over the life time of the duct system in

the mine opening. These supplementary apertures enlarge the density of leakage paths. This is the reason for representing an area of all apertures as a single narrow longitudinal aperture with equivalent width A*(See Figure 3).
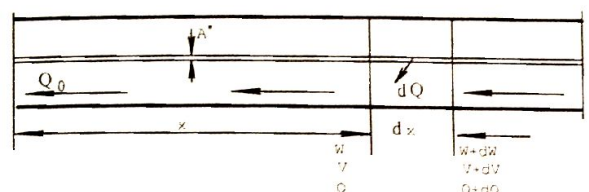

Figure 3. Model for a duct with longitudinal aperture

In the case of this model air leakage from the duct (air losses) is continuous. The flow rates of air in the duct and pressure loss, are functions of the length x and can be treated as continuous functions.

The air flow through duct from its energy aspect, can be described by Bernoulli's equation. This equation after several transformation according model mentioned can be given as:

$$B.V\dot{V}'' + \rho.V.\dot{V}'' - (\lambda/d)V^2(\rho/2) = 0 \qquad (9)$$

where; V = average air velocity in the duct; λ = dimensionless resistance coefficient and B=substitution.

There is no exact solution of the equation. For solving this particular problem the method of dividing the duct into short segments can be applied. The rate of leaking air and loss of pressure due to friction factor are determined for any particular calculation section.

Computers programs are developed for all afore mentioned algorithms,. Without them their practical application is impossible.

1.3 *Performance evaluations of existing avs*

For performance evaluation of an existing auxiliary ventilation system it's necessary to obtain some data by measuring. For an AVS with one fan mounted on the end of the duct it is necessary to measure the parameters as follows; Q_0, Q_f and P_f.

From the data obtained by measuring it is possible to calculate air delivery coefficient $\eta=Q_0/Q_f$ and to evaluate the quality of duct assembling. For evaluation of metal ducts assembling quality, the authors use the next relative scale which is relevant to a duct of length L=300 m;

1. Very good $\eta=0.9$
2. Good $\eta=0.8$
3. Satisfactory $\eta=0.7$

4. Unsatisfactory $\eta=0.6$
5. Bad $\eta=0.5$

From the value measured for P_V it is possible to calculate the friction factor for the duct (α).

2 DEVELOPING OF COMPUTER PROGRAM FOR DESIGNING OF AUXILIARY VENTILATION SYSTEMS

The present analytical systems have been successfully applied to developing the computer software package named *DAVentS*. The programs are written in *MS Visual BASIC Ver 5.0* and partly in *Visual C++ Ver.4.5* and can be run on any machine that operates the *Windows 95/98* platforms.

The basic structure of the program is shown in Figure 4.

The program main features include:
- Evaluating system parameters (ducts friction factor, resistance of leakage paths, air delivery etc.)
- Fans working parameters
- Fans allocation for long ducts
- Performance evaluating of active AVS
- Complete design of new AVS*
- All other most common tasks in the process of designing AVS

The program modules include algorithms developed from both physical models of leakage (*model for ducts with leakage through the flange joints and model for ducts with longitudinal aperture*), for comparison purposes.
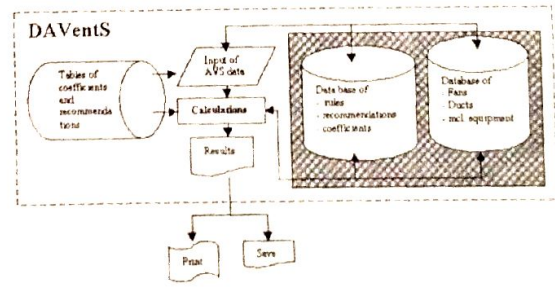

Figure 4. Program structure

DAVentS like all modern Windows based programs have more advantages:
1. Better user interface (easier data input)
2. Modular design(event driven program)
3. Open Databases
4. Recommendations and coefficients that can be changed
5. Online help and tool tips
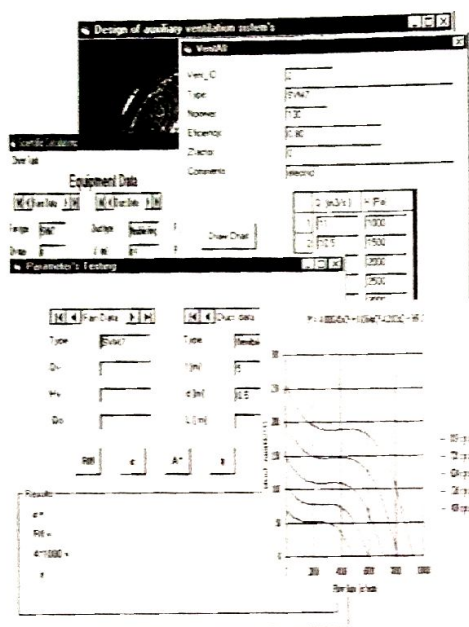6. Better display of results (graphics)

Figure 5. Program Windows
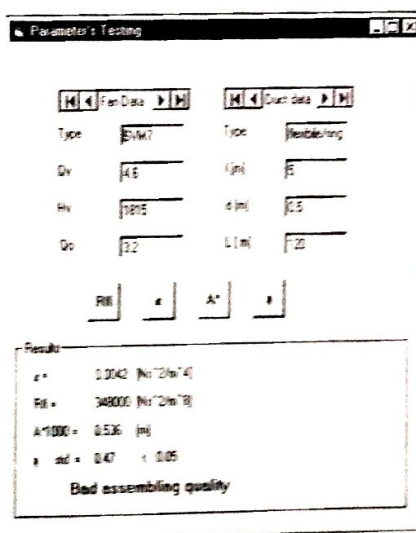
Program windows are shown on Figure 5.

Figure 6. Program window with obtained results

The paper will discuss only those features which are accomplished by algorithms presented before. Those features are:

- Calculating ducts friction factor α, resistance of leakage paths R_{fl}, equivalent width A^* (for II physical model) and standard air delivery factor η for known Q_f, P_f, Q_0 and L.
- Calculating max. duct length for given fan (Q_f and P_f) and duct (d, l, L, α, and R_{fl} or A^*)

parameters and air required at the face(Q_0).
- Calculating fan parameters for known L, α, and R_{fl} or A^* and Q_0.
- Calculating Q_0, Q_f, P_f and η for known fan type and duct length.
- Calculating multiply fans allocations for long ducts without recirculations.

Numerical examples and results obtained are given below.

3 NUMERICAL EXAMPLES AND DISCUSSION

Example 1: Given the blowing ventilation duct, with length L=150[m] and duct diameter d=0.5[m]. Unit duct length is l=5[m]. The following data are measured: Q_0=3.2[m³/sec], Q_f =4.6 [m³/ sec] and P_v=1815[Pa].

Using the DAVentS program the following results where obtained: α_d = 0.0042 [Ns²/m⁴], R_{fl} = 348000 [Ns²/m⁸] and A^*10^3=0.536 [m].

Values obtained can be used as input data for designing an AVS with approximately the same condition(See Figure 6).

For evaluation of the quality of duct assembling the authors use "standard air delivery factor-η" which is relevant to a duct of length of L=300 [m]. By the DAVentS software with data mentioned before as an input, value for η is calculated. According to the scale for evaluation for η=0.47 quality of duct assembling can be characterized as poor (See Fig. 6).

Example 2: Evaluate effects of the duct diameter on the parameters of AVS for consecutive data as an input: L=350[m], l=3[m], α_d=0.003[Ns²/m⁴] and standard η=0.8. Solutions are obtained with DAVentS program for fans VM-5m and VM-6m. Results are shown in the Table 1.

Table 1. Results obtained from the DAVentS

	Fan VM-5m			Fan VM-6m		
	d=.5	d=.6	d=.8	d=.5	d=.6	d=.8
Q_0	3.19	4.00	4.47	4.00	5.51	7.51
Q_f	3.80	4.75	5.60	4.75	6.55	8,50
h_f	2056	1343	461	3278	2539	1037
η	0.84	0.84	0.84	0.84	0.84	0.84

Results shown in the Table 1 illustrate very well known relationship between the duct diameter and fans static pressure; when the duct diameter increasing the fan static pressure drops.

Example 3. Heading of a long drivage is ventilated with exhausting ventilation system with maximum duct length L=900[m]. Evaluate effects of duct diameter on the number and locations of the fan along the drivage, considering the requirements for lack of polluted air recirculation. This is realized by providing the duct with a pressure lower then the pressure in the drivage.

Other required data inputs are: $Q_0=5[m^3/sec]$, $l=3[m]$, $\alpha_d = 0.003$ $[Ns^2/m^4]$. Three different combinations are calculated; for d=0.6, d=0.8 and d=1[m] and leakage path resistance coefficients 6100000, 1440000 and 448000 $[Ns^2/m^8]$. There are also three different fan types used, VM-5m, VM-6m and VM-8m.

The problem is solved by using the DAVentS software and results obtained are shown in Table 2.

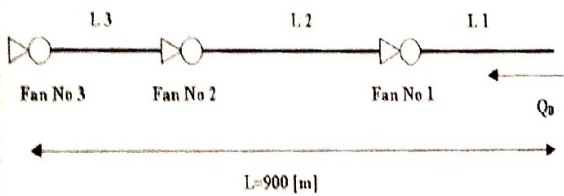Numbers of fans raising for the heading of the drivage (See Figure. 7)

Figure 7. AVS for long drivages

There could be significant energy savings if smaller fans are used in earlier fazes of driving the long drivage.

It is possible to optimize design of AVS, by the combination of presented aerodynamicall calculation and appropriate economic analyses for ventilation costs. Basic parameters in the optimization process are ducts diameter and fans type.

Table 2. Results obtained from the DAVentS

No	Fan type	L	ΣLi	Q_0	Q_r	h_r	η
d= 0.6		m	m	m^3/s	m^3/s	Pa	
1	VM-5m	102	102	5.0	5.32	669	0.96
2	VM-6m	285	387	5.23	6.4	2630	0.82
3	VM-6m	168	555	6.40	7.03	2223	0.91
4	VM-6m	120	675	7.03	7.44	1951	0.94
5	VM-8m	228	903	7.44	8.62	4144	0.86
d= 0.8							
1	VM-6m	447	447	5.60	8.19	1323	0.68
2	VM-8m	456	903	8.19	12.3	2943	0.68
d= 1.0							
1	VM-8m	900	900	5.4	14.3	1594	0.39

4 CONCLUSIONS

Algorithms for calculation of AVS parameters are basically developed by use of essential relationships from fluid mechanics. By applying this algorithms computer software package named DAVentS is developed.

In general, the program can be used for solving followed problems:

1. Performance evaluation of an existing auxiliary ventilation system, (See Example 1) and by use of data obtained from calculations to plan and realize practical steps for improving AVS efficiency.

2. Possibility for design of complex AVS with long ducts, when more than one fan is needed. determining of fans location along the duct in therms of no polluted air recirculation, use large diesel equipment, high rock temperature, etc.

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