

## DESIGN AND PERFORMANCE EVALUATION OF AUXILIARY VENTILATION SYSTEMS

D. G. MIRAKOVSKI

Faculty of Mining and Geology, Stip, Macedonia

V. KERTIKOV

University of Mining and Geology, Sofia, Bulgaria

**ABSTRACT:**The paper presents models of Auxiliary Ventilation Systems (AVS) with leaky ducts and algorithms for calculations of pressure loss, air leakage, volume flow ratio and pressure of fans. Two basic models of leaking ducts are discussed: 1<sup>st</sup> model for a duct with leakage through the flange joints; 2<sup>nd</sup> model for a duct with an equivalent longitudinal aperture. The present analytical system has been successfully applied to developing a computer program, named DAVentS. A sample problem is used to illustrate the efficiency and accuracy of DAVentS software in solving most common problems in the process of designing AVS.

### INTRODUCTION

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

- fan flow rate  $Q_f$  [ $m^3/sec$ ],
- quantity of air reaching the end of the duct  $Q_o$  [ $m^3/sec$ ],
- pressure loss  $W$  [Pa],
- pressure of fans  $P_f$  [Pa] which is equal to the pressure loss  $W$ ,
- coefficients which characterize the air leakage of the duct  $T$  and  $p$ , expressed by the following equations;

$$\eta = Q_o / Q_f \quad (1)$$

$$p = Q_f / Q_o = 1/\eta \quad (2)$$

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:

$$\Delta P_r = 6,5 \frac{\alpha \cdot L}{d^5} \cdot Q^2 = R \cdot Q^2 \quad (3)$$

where;  $\alpha$  is friction factor for the duct [ $Ns^2/m^4$ ] or [ $kg/m^3$ ]

$L$  - duct length [m]

$d$  - duct diameter [m]

$R$  - aerodynamical resistance of the duct [ $Ns^3/m^8$ ] or [ $kg/m^7$ ].

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; Brownifig, 1983; Vutukuri,1984;CalizayaandP. Mousset-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 sections 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) a model for a duct with leakage through the flange joints;
- b) a model for a duct with an equivalent longitudinal aperture.

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 imperfections assembling there are apertures of width  $A$  in the flanges between them, and air flow rates of  $\Delta Q$  leak through them.

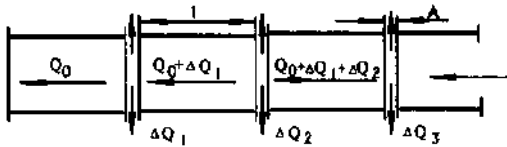


Figure 1. Model for a duct with leakage through the flange joint

Two calculating algorithms for this model are presented below [Dimitrov and 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 Fig.2) composed of simple parallel contours or meshes. There are three types of branches in the network.

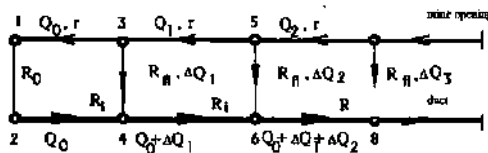


Figure 2. Representing AVS as ventilation network

Type 1; 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  $R_n$  [ $Ns^2/m^8$ ]

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

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:

$$R = R_1 / (1 + \sqrt{R_1/R_2})^2 ; Q = Q_0 \tag{4}$$

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

where;  $W = RQ^2$ ;  $R_1 = r + R_0 + R$ , and  $R_2 = R_{n1}$ .

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  $R_1 = R + r + R_{n1}$  and volume flow ratio through it is  $Q = Q_0 = AQ$ . Right hand parallel branch has a resistance of  $R_2 = R_{n2}$ . 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 calculated values of the rate  $Q$  and the loss of pressure  $P$ .

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

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

where  $A$  is the width of aperture (See Fig. 1), and  $\mu$  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  $\Delta Q$  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 (Qf and Pf respectively).

## 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 Fig. 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:

$$B.V.V' + p.V.V' - (\lambda/d)V^2(\rho/2) = 0 \quad (9)$$

where; V is average air velocity in the duct; X is dimensionless resistance coefficient and B is 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.

## 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; Q0, Qr and Pf.

From the data obtained by measuring it is possible to calculate air delivery coefficient  $\eta = QV/Qf$  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 Pv it is possible to calculate the friction factor for the duct (a).

## 4. DEVELOPING OF COMPUTER PROGRAM FOR DESIGNING AND EVALUATING AVS

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 Fig.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.

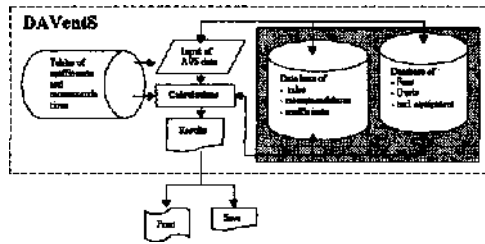


Figure 4. Program structure

DAVentS like all modern Windows based programs have more advantages:

- Better user interface (easier data input)
- Modular design(event driven program)
- Open Databases
- Recommendations and coefficients that can be changed
- Online help and tool tips
- Better display of results (graphics)

Program windows are shown on Figure 5.



Figure 5. Program Windows

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

Those features are:

- Calculating ducts friction factor  $a$ , resistance of leakage paths  $R_H$ , equivalent width  $A^*$  (for II physical model) and standard air delivery factor  $TI$  for known  $Q_f$ ,  $P_f$ ,  $Q_o$  and  $L$ .

- Calculating max. duct length for given fan ( $Q_f$  and  $P_f$ ) and duct ( $d$ ,  $l$ ,  $L$ ,  $a$ , and  $R_H$  or  $A^*$ ) parameters and air required at the face( $Q_o$ ).
- Calculating fan parameters for known  $L$ ,  $Q_o$  and  $R_H$  or  $A^*$  and  $Q_o$ .
- Calculating  $Q_o$ ,  $Q_f$ ,  $P_f$  and  $TI$  for known fan type and duct length.
- Calculating multiply fans allocations for long ducts without recirculations.

Numerical examples and results obtained are given below.

## 5. 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:  $Q_o=3.2[m^3/sec]$ ,  $Q_f=4.6 [m^3/sec]$  and  $P_v=1815[Pa]$ .

Using the DAVentS program the following results were obtained:  $a \cdot j = 0.0042 [Ns^2/m^4]$ ,  $R_n = 348000 [Ns^2/m^8]$  and  $A^* \cdot 10^3 = 0.536 [m]$ .

Values obtained can be used as input data for designing an AVS with approximately the same conditionnée Fig.6).

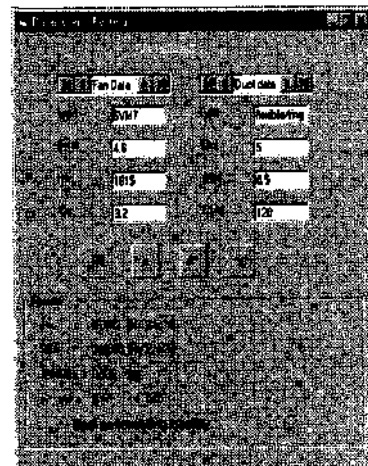


Figure 6. Program window with obtained results

For evaluation of the quality of duct assembling the authors use "standard air delivery factor- $r_i$ " 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  $r_i$  is calculated. According to the scale for evaluation (See 3.0) for

$T=0.47$  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:  $L=350[m]$ ,  $l=3[m]$ ,  $Od=0.003[Ns^2/m^4]$  and standard  $T=0.8$ . 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
$Q_r$	3.80	4.75	5.60	4.75	6.55	8.50
$h_r$	2056	1343	461	3278	2539	1037
$\eta$	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 than the pressure in the drivage.

Other required data inputs are:  $Q_0=5[m^3/sec]$ ,  $l=3[m]$ ,  $Od = 0.003 [Ns^2/m^4]$ . Three different combinations are calculated; for  $d=0.6$ ,  $d=0.8$  and  $d=1[m]$  and leakage path resistance coefficients 100000, 1440000 and 448000  $[Ns^2/m^4]$ . 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 Fig. 7)

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

It is possible to optimize design of AVS, by the combination of presented aerodynamical 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	Li	$Q_{r0}$	$Q_r$	$h_r$	$\eta$
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

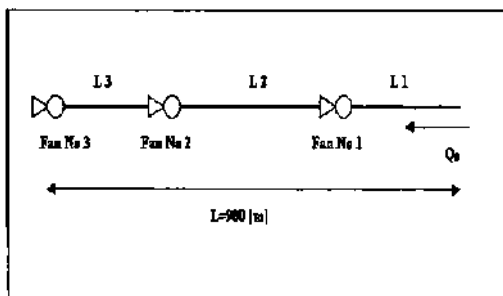


Figure 7. AVS for long drivages.

## CONCLUSION

Algorithms for calculation of AVS parameters are basically developed by use of essential relationships from fluid mechanics. By applying the 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 terms of no polluted air recirculation, use large diesel equipment, high rock temperature, etc.

## REFERENCES

- Browning E. (1983), "An Approximate Method for Auxiliary Ventilation Calculations", *The Mining Engineer, September*, p.p. 129-134.
- Calizaya F, Mouset-Jones P.( 1993) "A method of designing auxiliary ventilation systems for long single underground openings" Chapter 37. *Proceedings of the 6th US Mine Ventilation Symposium*, p.p. 245-250.
- Dimitrov G, Kertikov V, (1988) "Airdinamical calculations of an auxiliary ventilation system by the use of a PC", (Bulgarian language). *Annual of the Higher Institute of Mining and Geology. Vol. XXXIV*, 1988, Part I, p.p. 181-189. Sofia.
- Kertikov V, ( 1994) "On the methods for aerodynamic dimensioning of AVS with leaky ducts" (Bulgarian language). *Annual of the University of Mining and Geology*, Sofia, p. 97-102.
- Kertikov V, (1996) "Design for Auxiliary Ventilation System with Leaking Ducts" *Underground Mining Engineering*, No 5. Belgrade.
- Pawinski J, Roszkowski J, Strzeminski J, (1979), *Przewietrzanie kopaln*. Katowice, p.p. 343-349.
- Voronin V, (1951), *"Osnovi Rudnichnoj aerogazodinamici"* Moskva, p.p. 262-271
- Vutukuri V, (1984), "Design of Auxiliary Ventilation Systems for Long Drivages", *5th Australian Tunneling Conference. The Institution of Engineers*, Sydney, p.p. 73-79.