

Automated Regulation of Mine Ventilation

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SYNOPSIS

The ventilation system of the Pyhasalmi Mine is described. The mine is located in an area where the annual atmospheric temperature may vary from +30°C to -30°C. Natural ventilation causes serious difficulties because the underground mine is connected by drifts and finger raises to the bottom of the 120 m-deep open pit.

The natural ventilation tends to make the ventilation net unstable. The paper describes how the instability characteristics of the ventilation net can be studied and how they have been taken into account when automating the control of the ventilation. In addition, the software, hardware and costs of the system are described. The system consists of 12 automated ventilation doors, two mine fans, 8 elements for sensing the air flow and temperatures, a control panel and a process computer.

INTRODUCTION

The Pyhasalmi Mine of the Outokumpu Co. is one of the largest in Finland. At present 800 000 metric tons of copper, zinc and pyrite-ore are mined annually, of which almost two-thirds is mined underground. Over half a million tons of various concentrates are produced per year, of which 85 per cent is pyrite concentrate, 10 per cent zinc concentrate and five per cent copper concentrate. The pyrite concentrate is treated in the pyrite smelter of the company, yielding elemental sulphur, SO₂ gas, iron oxide cinders and electric power.

The mine is located in central Finland, where the annual atmospheric temperature varies from +30°C to -30°C. The temperature variation results in ventilation problems because the open pit and underground stopes are connected by several ore passes and drifts on the bottom and sides of the open pit. Efficient air conditioning is also necessary because of the possibility of high concentrations of SO₂ and H₂S gases, which originate in pyrite-dust explosions, and because of the use of diesel machinery.

In the air conditioning problem there are generally three kinds of variables:

- (i) Variables of the air composition.
- (ii) Variables describing the mine: lengths and cross-sections of drifts, raises and stopes and how these branches are connected to each other.
- (iii) Variables of the kinematics and physical state of the air everywhere in the mine.

The variables in the first group are determined by the general atmospheric conditions and by the effects of explosions or blasting on the concentrations of dust and gases. The variables in the second group are defined when the mine is being planned. Thus the variables of group (i), and partly of (ii), are, from the ventilation point of view, uncontrollable. The usual initial situation is that the ventilation net is given and the goal is to control some variables in the third group so as to obtain a specified flow of fresh air to certain places in the mine.

Of the variables in groups (ii) and (iii), those which are to some extent directly controllable are the total air quantity blown into the mine, the mean air temperature in the mine, and the distribution of the total air flow in the drifts. Because of the functional dependence between the pressure losses in the drifts and the respective air flows, the loss of pressure energy in the drifts is as indirectly controllable as the air flow.

Technically, these variables are controlled by air-heating units, fans and ventilation doors.

For the ventilation of the Pyhasalmi Mine the most serious difficulty arises from the large seasonal variation in the atmospheric air temperature. This results in uncontrollable sources of natural ventilation pressure in the system. These sources tend to disturb the air circulation and make the system unstable in certain circumstances. Figure 1 is a diagram of the mine. The air flow in the mine as a result of natural ventilation, when all ventilation doors are open and the fans are not functioning, is indicated by arrows. However, the desired air flows are, nearly everywhere, in the direction opposite to the flows created by the natural ventilation, since during the winter the air is heated and blown down the ventilation shaft (on the left in Fig. 1). At present the major portion of the air is taken to level 210 and distributed to the stopes. A minor portion is currently led to level 400 in order to ventilate the crushing stations. Later, level 400 will be the main ventilation level. The air flows of the net vary from 0 to 200 000 m³/h and its temperature and relative humidity are, independent of the weather, 6 to 8°C and greater than 90 per cent, respectively.

The goal for the automation of the ventilation can now be stated as follows:

Independently of the uncontrollable natural ventilation and the random disturbances from the operation of the mine, specified quantities of fresh air are to be blown to the work places. This also includes the requirement that the stopes must be ventilated after blasting. Besides the above goal there are the following constraints and auxiliary requirements for the solution of the problem:

- (i) The costs of heating the air should be minimized.
- (ii) Freezing in any part of the mine should be prevented.
- (iii) The control elements (doors, fans) should not seriously disturb the traffic in the mine.
- (iv) The control system should be so designed that the goal can be maintained even after considerable drift and stope alterations in the mine.

Familiarity with the stability characteristics of the ventilation net is of primary importance for automatic control of the ventilation. For this reason one example of the Pyhasalmi net will now be analyzed before the system currently in use on the mine is described.

THE STABILITY OF THE VENTILATION

A change in the resistance to air flow in any one drift will result in changes in the air flow quantities, and possibly also in the direction of flow, in other branches of the ventilation net. Being able to predict the extent of these changes is

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important for the effective control of the net. We shall call these two responses *the quantity instability* and *the direction instability*. In this study we also consider the stability of the mean air flow. Rapid fluctuations due to the turbulent nature of the air flow or disturbances of short duration caused by traffic in the mine are considered to be 'noise'.

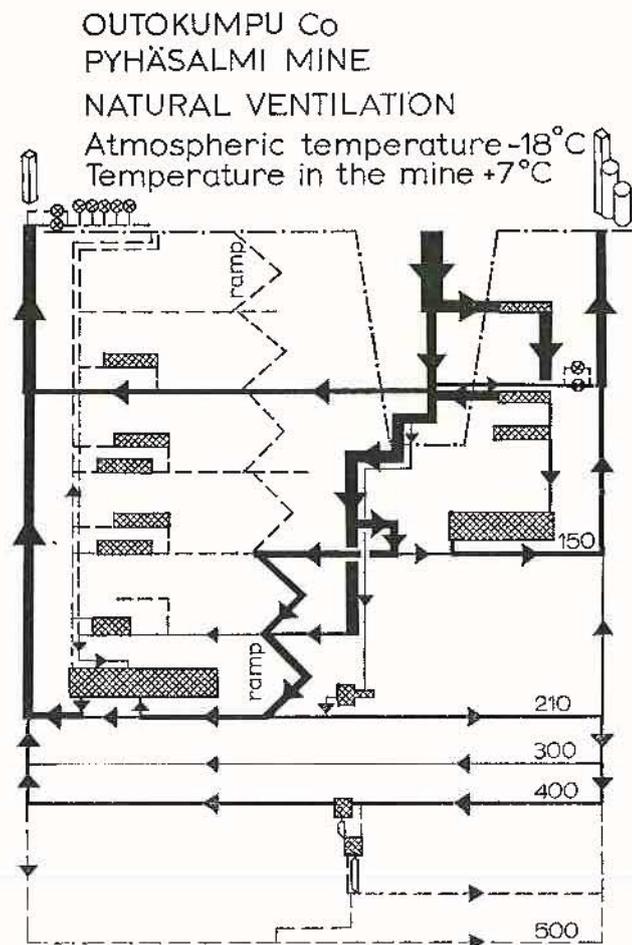


Fig. 1. Natural ventilation of the Pyhasalmi Mine. On the left is the ventilation shaft. Arrows indicate the tendency for air flow in cold weather due to natural ventilation pressures.

Furthermore, the opening of ventilation doors and changes in the natural ventilation pressure will change the pressure structure in the net so that a branch can be stable in some situations and unstable in others. The criteria for changes in stability can be studied using two computer programs:

- (i) The digital simulation model of the mine. The measurements in practice have proved the model to be sufficiently accurate for the simulations.
- (ii) The computer program to localize branches which may be direction-unstable.

If the pressure decreases from A to B in Fig. 2 then branches 1 to 4 will have stable flowing directions whatever their air resistances are, but branch 5 has a special position in the net structure. When the resistances are increased in 1 or 4 it is possible that the pressure head P_{1-2} will change and the air flow in branch 5 will be reversed. Such branches are called *diagonal branches*.

Diagonal branches are very common in complicated ventilation networks and it is difficult to locate them. Moreover, if the flow reverses in one diagonal branch then a change in

another branch or a complex of several branches may be possible. Thus the possibility of instability is ranked so that the first diagonal branch is of *first order* and diagonal branches caused by the first one are *higher-order diagonal branches*. The first-order diagonal branches are the most unstable and only they are considered in this paper.

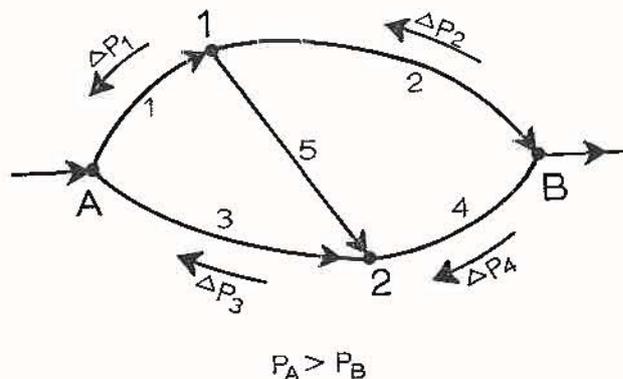


Fig. 2. Branch 5 is a typical diagonal in the ventilation net. If the air resistance of 1 or 4 is increased the flow in 5 can reverse.

A first-order diagonal branch need not necessarily be direction-unstable; it depends on the pressure structure of the net. Using the notations in Fig. 2 it can be stated that the diagonal branch is stable if

$$K = \frac{\Delta P_3 \Delta P_2}{\Delta P_1 \Delta P_4} > 1.$$

The simplified ventilation network of the Pyhasalmi Mine is shown in Fig. 3. When the direction stability of the net is analyzed by the method of Henningsen (1971) it shows that branches 57, 60, 68, 71, 73, 76, 77, 80, 91, 94 and 111 are first-order diagonals (higher-order diagonals are omitted here). If one wishes to study the K -value of these diagonals their environment must be simulated. The K -value will change if the position of a ventilation door is changed or when the natural ventilation pressures vary. The natural ventilation affects branches 80, 84, 91, 102, 118 and 122 and is (in winter) in the opposite direction to the arrows in Fig. 3. Branch 80 is stabilized by the auxiliary mine fan, in branch 91 the natural ventilation dominates branches 77, 94 and 111 are of minor importance. The K -values for the more important branches 57, 60, 68, 71 and 76 have been calculated, see Table I.

One of the goals for ventilation in the state of the mine in Fig. 3 is to blow certain flows of heated air to branches 47, 75 and 114. Because the natural ventilation will hinder this task markedly and is an effective source of direction and quantity instability, the target air flows are also shown in Table I.

The net structure in Fig. 3 can be called a *base structure* in which the branches mentioned above are first-order diagonals. The flow directions in this base structure can be changed by the natural ventilation, resulting in a new base structure with new diagonals of the first order. This can be seen in Table I. In some situations the air will flow into the mine through 122 and the base structure for the stability study is changed. In the new structure, branches 68 and 76 are no longer diagonals.

Among other things, Table I shows that the air flow in branch 114 is too small. Because of that, raise 92 must be widened in order to get more air to the stopes in node 8.

Legend:

-  vent. door
-  regulable vent. door
-  mine fan
-  air quantity sensor

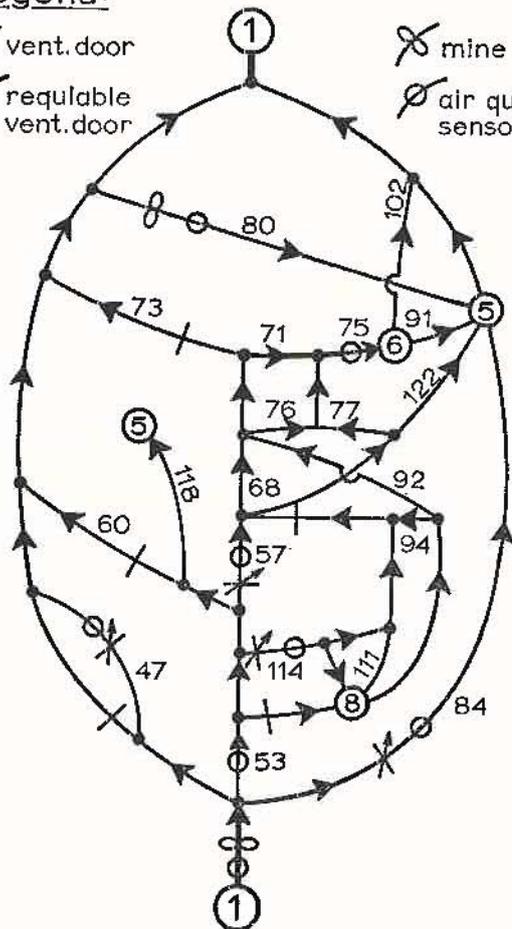


Fig. 3. Simplified ventilation net of the Pyhasalmi Mine. The air is blown into the mine from the atmosphere (node 1 down in the figure). Node 5 is the open pit and the slope areas are shown as nodes 6 and 8.

Furthermore, the table shows that diagonals 57 and 60 will not be unstable. This means that the respective ventilation doors will be effective for control in all situations.

The following stability characteristics can be stated as a summary:

- (i) The energy of the mine fans and the natural ventilation together cause a base structure of the air flow in the mine.
- (ii) When the energy of the natural ventilation changes sufficiently the air flow will reverse in some branches, resulting in a new base structure.
- (iii) When a particular base structure predominates the possible diagonal branches can be found and their sensitivity for instability can be evaluated.
- (iv) When the characteristics of the mine change, the stability of the branches will change and a new study will be needed.

THE CONTROL SYSTEM

The present control system consists of the main mine fan, the heating units for blown air, one auxiliary fan and 12 automatic ventilation doors of which four can be regulated continuously. Control is possible either manually from a control panel or automatically by a central control unit. The sensing elements are eight instruments for measuring air velocity, and thermometers. The control and sensing elements are connected by cables to the panel and from there will be connected to the computer. Door positions and air flow values are displayed on the panel (Fig. 5).

TABLE I

THE VARIATION OF THE AIR FLOW (Q) AND THE STABILITY COEFFICIENT (K) OF SOME BRANCHES IN FIG. 3 AS FUNCTION OF THE ATMOSPHERIC TEMPERATURE AND THE STATES OF VENTILATION DOORS.

Opened doors	Branch	Atmospheric temperature					
		+20°C		+7°C		-30°C	
		Q(%)	K	Q(%)	K	Q(%)	K
114	53	100		94		66	
	57	16	10	15	10	10	7
	60	7	86	8	102	9	246
	68	31	4,4	31	4,4	43	stable
	71	11	1,2	11	1,3	27	1,2
	76	12	7	12	3,3	13	stable
	47	20		21		23	
	75	49		49		96	
	114	14		14		9	
	73,114	53	115		111		86
57		20	32	20	29	17	19
60		5	8	5	8	6	10
68		45	stable	46	stable	58	stable
71		-30	0,7	-36	0,6	-57	0,5
76		14	stable	13	stable	12	stable
47		17		17		17	
75		13		7		17	
114		18		18		15	
all doors		53	71		67		43
	57	51	2,3	52	2,4	31	1,9
	60	13	1,1	18	1,2	36	2,6
	68	49	6	50	7	57	stable
	71	-6	1,0	-10	1,0	-23	0,9
	76	17	4	18	4	16	stable
	47	48		47		44	
	75	36		35		52	
	114	-18		-17		11	

Generally, the automated system works so that, depending on the current production (and requirements for air), the operating supervisor chooses a ventilation strategy from the panel. The required air flows and the states of the on/off doors are stored in tables in the computer's memory. The computer maintains the desired strategy by controlling the main mine fan and the four continuously adjustable doors so that the measured and required air flows are equal.

Ventilation strategies

The two separate slope areas (as nodes 6 and 8 in Fig. 3), the inclined ramp (branches 57, 68, 76) and the crushing station (47) are to be ventilated individually or in combination depending on the work in the mine. The combination of these demands makes seven different ventilation strategies. Because of the goal of minimizing the total air flow needed in winter, there is one more strategy for the case when the mine is not working.

Blasting situations

The automated ventilation doors are metallic roller doors and they must be opened before blasting is done in the mine. Because of this and the danger of pyrite dust explosions, blasting in the mine has been centralised at five blasting stations, from where the 12 automatic doors can be opened before firing. Furthermore, the computer will be informed about where blasting is going on. After blasting the computer will perform the desired 'blasting ventilation' strategy (in the current state three different possibilities) and then return to the ventilation strategy which was current before blasting operations.

Alterations in the mine

The ventilation net will change along with changes in the mine and therefore also the most effective locations of ventilation doors and air velocity sensors will change. Alterations in the ventilation net in the coming five years have been simulated by the computer model in order to locate the current doors and air velocity sensors optimally. It is also possible by simulation to predict the number of control and sensing elements needed in the future, which is important when planning the stem net of cables, dimensions of instrument panels and the software of the system.

Because all the parameters of the system are stored as tables in the software, their value or number can be changed easily (Fig. 4).

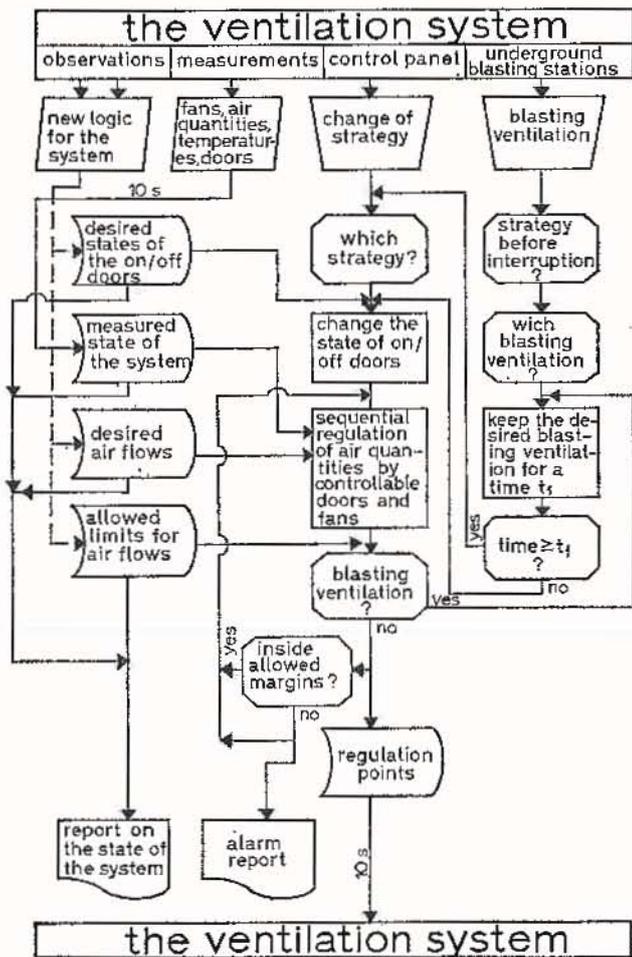


Fig. 4. Logic of the control system.

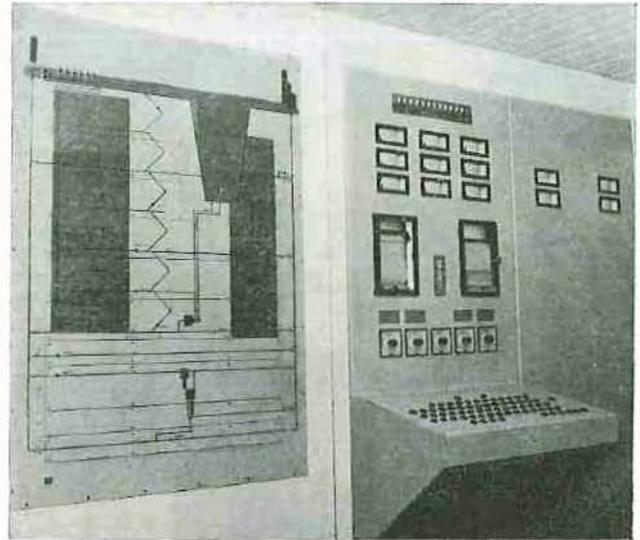


Fig. 5. Control panel. On the right are the dial plates of instruments and control buttons.

Cables

The Pyhasalmi ore is a pipe-like formation and therefore the horizontal dimensions of the mine are small. The stem of the cable net is about only 1,6 km long. The stem consists of two cables, the control cable (voltage control) and the cable for measuring (current) signals. These cables have, respectively, 50 and 20 pairs of wires. The cables are drawn from the control room down the main shaft to level 150, and from there through drill holes one part is drawn up to levels 100 and 68 and another part down to level 210. The cable connects the devices on level 210 and then continues down the ventilation shaft to levels 400 and 500. A total of about 200 m of the cable stem is drawn through drill holes.

Measurement of air flow

The sensing elements for the measurements are hot wire (Ni) anemometers, which are mounted stationary about 0,5 m from the roof of the drifts. The sensor reacts to changes in the air velocity. Their meters in the control panel are calibrated to show the respective air flows.

Ventilation doors

The automated ventilation doors are motor-driven metallic roller doors (Fig. 6). The opening of a door is indicated by a light on the control panel and the states of the adjustable doors are recorded. The doors can be opened by the computer, or manually from the panel, from all the five blasting centres, and from the door frames. They can also be opened from a distance of about 20 m in the drifts, where there is truck traffic, without needing to stop. When the door is opened from the blasting centres or from the respective drift it will be closed automatically. If automatic control is on, the opening of a door manually causes that door to be switched off from computer control. After a certain period of time control returns automatically to the computer.

Computer

The planned central control unit is a minicomputer with 8 K memory capacity, and peripheral equipment consisting of punched tape and line printer devices. The computer and the button and relay interfaces to the process are situated in the control room.

INSTRUMENTS AND CONTROL DEVICES

Control panel

All the control and sensing elements are connected by cables to the control panel. The control of doors and fans can be done by buttons and potentiometers. At present there are mounted in the panel two six-point recorders for recording continuously the air flows, the positions of the adjustable doors and the air flows of the fans. The states of the doors are also shown by a light in the process diagram on the panel. In addition there are 13 dial plates for the instruments measuring air flows and temperatures (Fig. 5).

COST OF THE SYSTEM

The investment costs of the control system described in this paper are as follows:

	%	%
Engineering work		
Planning	18,0	
Simulations by computer	3,0	
Programming	8,5	29,5
Ventilation doors		12,5
Measuring instruments and their installation		10,0
Control panel		2,5
Regulators		4,5
Cables and their installation		8,5
Blasting centres		1,0
Process computer and periphery facilities		29,0
Others		2,5
Total		100,0

This total initial investment is about seven per cent of the annual mining cost.

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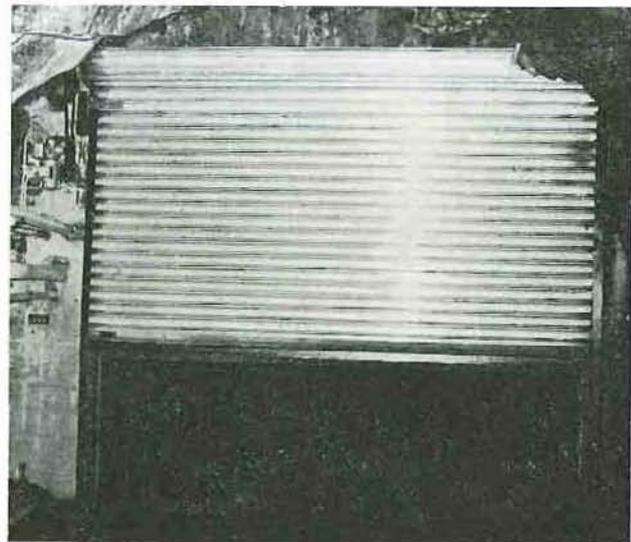


Fig. 6. Automated ventilation doors are motor driven metallic roller doors.

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