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Reversal of underground mine ventilation

Reversal of main ventilation is one of the important means to isolate a fire during emergency. In America, it has been reported that by fan reversal lives have been saved in underground coal mine. Indian coal mines have so far not come forward to adopt this method. Not much research work has so far been carried out in India. This paper deals with international review of the work carried out in other countries. Law relating to reversal of ventilation in different countries of the world is discussed. The effect of reversal on goaf gases and adjustment of ventilating flow is also outlined.

Introduction

During emergencies due to fire in a mine it may be desirable to reverse the air flow of main mine fan to provide an escape way or isolate the fire. The kind of emergencies are open fires in the main intake airways near the downcast shaft and immediately after explosions have occurred in the intake airways. The main purpose of reversal of fan is to prevent the poisonous fumes from the fire from flowing inbye and polluting the whole of the mine atmosphere with danger to life. The decision to reverse the ventilation is a difficult proposition to make and should be implemented only after careful examinations of the situation which indicates that this would be advantageous in saving life and property.

Outbreak of fire in main intake airway close to downcast shaft of New Kenda Colliery, ECL in 1994 where 55 persons died is a sad example of mine disaster in Indian mining history. Decision to reverse the main mine fan could not be made probably because of lack of basic data on fan reversal and uncertainty about the exact location of survivors.

The following points may be considered before taking the decision (Prasad & Rakesh, 1992):

- The position of the fire in the intake air-path and its extent, position of possible survivors
- Workplace environment presence of noxious and inflammable gases and temperature.
- Likely danger of explosion
- If the fire/explosion has affected only the faces and the return or the intake haulage roadways
- If the explosion has caused a fire in or near the downcast shaft/incline or in the intake near the face

Apart from above the type and condition of fan and arrangement for reversal are to be examined. The amount of air flow through the mine after reversal has to be taken into consideration.

To generate basic data for fan reversal like pressure developed, air flow rate and fan efficiency etc., comprehensive study is an urgent necessity.

Law relating to reversal of ventilation

The first enactment in USA making provision for arrangements to reverse the ventilating current was included in the Coal Mines Act, 1911. Section 31(3) required that after Ist January, 1913 or such later date as in view of the circumstances of the mine may be fixed by the Inspector of the division, there shall, in every mine in which a mechanical contrivance for ventilation is used, be provided and maintained in a condition to be put into immediate operation adequate means for reversing the air current (Hinsley, 1966).

Russian mine regulations require that main mine fans be equipped with reversing facilities to enable the air flow to be reversed within 10 minutes if required in emergencies. Axial flow fans are fitted with reversing drifts to meet this regulation (Hinsley, 1966).

As per Coal Mines Regulation, 1957 and Metalliferous Mines Regulation, 1961 in India every main mechanical ventilator in coal mines, and every mechanical ventilator (other than an auxiliary fan) in metalliferous mines, shall be so installed, designed and maintained that the air current can be reversed when necessary. Regulations are however silent about the conditions under which ventilation reversal is to be effected.

However, in many countries reversal of fan is not permitted under any circumstances. In Australia there is no legislation requiring the ability to reverse the ventilation flow in underground coal mines. Most of the Australian mines

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have methane gas in goaf areas which would make reversal of the ventilation a high risk option. They also have a very important regulation which requires two separate airways into the mine.

Reversal arrangements

In case of centrifugal fan, the fan impeller continues to rotate in its normal direction and the air current in the mine is reversed by rearranging a system of doors connected with the ventilator housing. Fig.1 shows the reversal arrangements of centrifugal fan. Additional air-passages must be constructed together with necessary doors to course the air to reverse whilst the fan continues to run in its original direction.

In case of axial flow fans reversal of the air could be readily accomplished simply by reversing the direction of rotation of the motor by using a reversing switch. A common practice is to interchange the leads either at the motor terminal box or in the starting unit (Prasad & Rakesh, 1992).

This practice is not only time consuming but also deals with avoidable risks to the workers. So it is advisable to install a double-throw air break reversing switch before the starting control gear of the ventilator motor. The C.I.M circulars suggest that reversing switch should be kept under lock, with the key in the custody of the authorised fan attendant. Since the decision of reversal is to be taken, under emergency situations, only by the manager it is obvious that the key should be with him. The ILO code (1986) recommends that the reversing system provided with the main mechanical ventilator should be regularly tested.

The efficiency will be reduced when the fan is reversed owing to the difference in shape between the back and front of the blades. Steart, 1924 considered that the circumstances in which reversal is necessary efficiency is of little or no importance. A permanent reversal arrangements can be effected in a short time by taking the air-screws off the shaft turning them round and replacing them. Reversal of the direction of rotation then reverses the ventilation efficiently. In case of variable pitch fan, pitch would be reversed simply by turning them to face in the opposite direction at the same angle of incidence. When reversal is needed, a double-thrust bearing is, of course, required.

International experience with reversal

Literature on ventilation reversal in mine is very limited. A few available literature are discussed below.

There are two reasons why the air flow is reversed in the mines of USA. These are: (i) to prevent ice build up in the intakes in winter (ii) to facilitate reaching the seat of underground fires without passing through the smoke and to allow safe transportation of material required for building stoppings.

In the USA, most of the mines are having facility to reverse the main mine fan. They have large areas of coal lying close to the surface, mostly flat and relatively free from methane. It has been reported that there were 10 disasters where air flow was reversed after the disaster by the use of the fan and in five of these there was saving of life. The total number of lives saved amounted to over 500 (Harrington and Von Bernewitz, 1924). There is not a single instance of loss of life directly or indirectly caused by reversal of the direction of air current. Some researchers (McElroy, 1925) advocated that the reversing arrangement should be installed regardless of whether the necessity for it can be foreseen or not. It is primarily an insurance against unforeseen happenings and as such has proved its worth in a number of instances. It has been strongly felt that lack of reversing arrangements has been held responsible for loss of life and property in some of American greatest mine-fire disasters.

In Russia, axial flow fans generally serve as main mine fan and are fitted with reversing drifts to meet the Russian mine regulations. The purpose of reversing duct is to increase the amount of reversed flow obtainable. This arrangement would allow the fan to continue to run in its designed direction. This would ensure full ventilating pressure of the fan.

Testing

Reversal arrangement in fan requires an extra reversal duct containing a number of bends. Thus a fan in reversed condition may circulate a smaller flow than in normal condition. The energy losses in the reversal duct however can be minimised by careful design of reversal arrangements (Gill, 1966). It has been reported that the flow could be maintained as much as 90 per cent of normal flow. Lindley and Hay, 1929 state that in general flow obtained is two-third of the normal flow. Study conducted by Engineers International, Inc., Westmont, Illinois showed that the quantity in the reverse mode ranged from 30 to 65% less than in the forward mode and the static pressure was directly proportional to the square of the quantity. Hinsley (1966) reports that reverse rotation of an axial flow fan produces in general less than 50 per cent of forward flow and in the case of two stage fans may be very much less than this.

MacFarlane, 1957 has reported the results of reversal tests on guide-vane axial flow fans. The results are given in Table 1. Guide-vane axial fans with one and two stages were tested and no adjustments were made to the fans before reversal. The volume at the design point of the fan with the forward direction of rotation is taken as 100 per cent volume flow.

Morris and Hinsley, 1951 made comparison between the performance of forward and reverse running of two stage axial flow fan. The fan was of 762 mm diameter with fixed-guide blades running at 1000 rpm. Three values of system resistance have been selected, corresponding to the points of maximum efficiency for forward running. The results are given in Table 2.

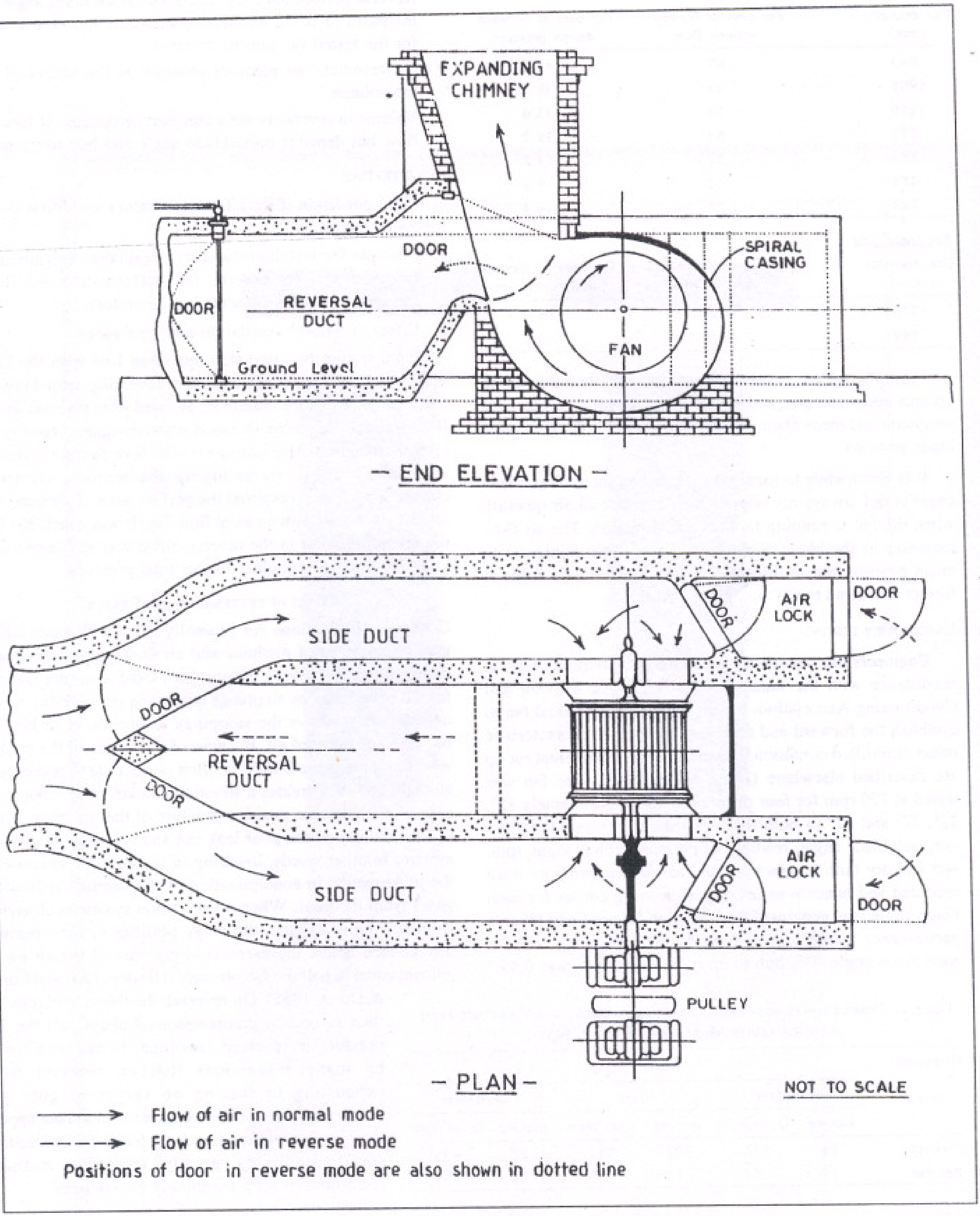

Fig.1 Reversal arrangements of centerifngal fan (after Deshmukh, 1984)

Table 1 : Reverse running of axial-flow fans (after MacFarlane, 1957)

Single stage fans

Fan diameter (mm)	Per cent of forward volume flow	Per cent of forward design pressure
889	67	45.0
1905	62	38.5
2286	58	33.6
572	54	29.2
889	37	13.7
889	31	9.6
889	25	6.3

Two stage fans

Fan diameter (mm)	Per cent of forward volume flow	Per cent of forward design pressure
1778	40	16.0
889	35	12.3

From the table it is clear that an appreciable reduction in volume and water gauge was noticed in the ratio of 3 to 1 for minimum and mean blade settings and 4 to 1 for the maximum blade position.

It is worthwhile to mention here that an increase in blade angle is not always accompanied by increase in air quantity when the fan is running in a reverse direction. The air flow increases as the blade angle is increased from minimum to mean position but no increase occurs as the blade angle is further increased to the maximum position.

Laboratory testing

Engineers International, Inc carried out laboratory tests in accordance with the standards set by the Air Moving and Conditioning Association, Inc on 2.4 m dia vane axial fan to establish the forward and reverse performance characteristic under controlled condition. Details of the experimental set up are described elsewhere (Dunn et al., 1982). The fan was tested at 720 rpm for four different blade angles namely 12°, 22°, 32° and 42° in both the forward and reverse direction. For each blade angle, readings of pressure, power input, rpm, wet and dry bulb temperature and barometric pressure were recorded and hence a series of performance curves for each blade angle was generated to determine forward and reverse performance, percentage of forward flow when reversed for each blade angle. The hub to tip ratio maintained was 0.45.

Table 2 : Comparison of forward and reverse running of a two-stage axial flow fan (after Morris and Hinsley, 1951)

Direction of rotation	Blade Setting					
	Minimum		Mean		Maximum	
	mm,wg	Q, m³/min	mm,wg	Q,m³/min	mm,wg	Q, m³/min
Forward	71	170	107	311	122	436
Reverse	10	57	11	99	8	108

After detailed analysis of the results obtained from laboratory testing it was concluded that

- Reverse performance (Pr) decreases as the blade angle (B) increases Pr α 1/B and this relationship may be true only for the tested fan hub to tip ratio.
- On reversal, fan pressure changes as the square of the fan volume.
- Volume in reverse is not a constant percentage of forward flow but depends upon blade angle and hub to tip ratio.

Field testing

Field condition differs from laboratory condition in the following manner.

1. Multiple fan installations, doors, regulators and auxiliary fan would affect reverse fan performance and these features cannot be simulated in laboratory.
2. Effect of natural ventilation and goaf gases.

Field testing is a two-step operation first with the fan's normal exhausting mode and then reversing with blowing mode. Sufficient time should be allowed after reversal for air flow through the mine to reach a steady state. Dunn et al. (1982) carried out field testing on axial flow fan and reversing was achieved by interchanging the motor's electrical connections. They compared the performance of forward and reverse operation with an axial flow fan. It was concluded that the operating point in the reverse mode was at considerably less volume and at slightly higher total pressure.

Effect of reversal on goaf gases

Goaf areas in the mine are generally filled with gases which may be mixtures of methane and air or in some cases black damp and air in varying proportions. Goaf areas are isolated from the workings by stoppings of varying permeability which unfortunately allows the stoppings to breathe in or breathe out small quantity of air. Because of the nature of the ground where stoppings are built it is often impossible to make them air-tight and thus creates a situation conducive to leakage. In case of considerable positive pressure of the stoppings some of the contents of the goaf leak out and enter the ventilation system. In other words, lowering of the absolute pressure in the mine results in contamination of the ventilating flow by gases from the goaf. When a ventilation system is changing from forcing to exhaust the inbye portions of the workings are reduced below the barometric pressure of the air by an amount equal to half the fan pressure (Hinsley, 1966 and Carter & Durst, 1955). On reversal, the inbye workings are then subject to compression of about half the fan pressure in reversed condition. It has been found by many researchers that on reversal from exhausting to forcing no surges of goaf gas involving increased percentages of methane appear to occur but on changing from forcing to exhausting surges involving greatly increased methane concentrations are commonly encountered.

While going for reversal due consideration must be given when mines are connected underground. The rise of absolute pressure on reversal could easily cause difficulties in the connected mines. If the exhaust ventilation is replaced by forcing flushes of polluting gases from the goafs may cause danger.

Adjustment of air flow

Apart from reversal of air flow it is also advisable to adjust the air flow from surface itself during a fire. It is established that ventilation changes made at the surface fan are fully effective within minutes underground (Hinsley and Jones, 1959).

Some researcher (Dyer, 1963) opined that reducing the air flow over an open fire in a mine roadway not only tends to reduce the intensity and rate of advance of the fire, but at the same time tends to increase the opacity and the toxicity of the smoke produced by the fire. This is in conformity with the results obtained by Singh et. al., 2000. They have conducted experiment in small scale mine fire model gallery at CMRI. The model is 19 m long; 10m of which is having rectangular cross section of 45x57 cm and rest 9 m having circular cross section of 0.3 m diameter. The coal lining, 5 cm thick is maintained at 1 m from the entry and up to a distance of 3 m. Two sets of experiment have been conducted establishing a velocity of 1 and 1.5m/sec. to monitor various parameters like pressure across fire zone, velocity of air, concentration of gases like CO_2, CO, O_2, temperature and dust particulate matters at different points of the gallery. Critical analysis of these results indicate that flow of air inside the gallery is directly proportional to the generation rate of CO, CO_2 and heat.

Remotely operated reversal system

For largescale or old mines, multi-upcast shaft and multi-ventilation horizon it is very difficult to eliminate the fumes/ toxic gases from inside the disaster district. This often calls for remotely controlled reversal system in fire affected district. The control system of ventilation reversal in district consists of hydraulic driven system, electro-control system and their connector-electromagnetic valves. Details of the system are described elsewhere (Zhiqian et. al., 1988). After the district reversal measures are taken, the smoke from the disaster-affected district will go through the major return airways of the mine to surface instead of whole reversal of the mine.

Conclusions

The question of whether the need is simply one of reversal of the air current or of full and adequate ventilation of the mine with the air flow reversed requires consideration. Implementation of full reversal of ventilation in a mine requires extensive modifications below ground. To make reversal of air-current a effective measure to isolate fire, conditions of a particular mine should be well known. Position of fire in a mine plays an key role in this regard. If the positions of fire are some distance inbye, then some preparations both underground and to the surface air-lock would be required to prevent doors blowing open when the flow is reversed.

In some situations, quick reversal would be an advantage as it would enable the route taken by toxic fumes to be changed, so that men inbye of the fire would be provided with a safe way of escape.

Additional expenditure is involved in case of reversal arrangements with the centrifugal fan.

There is an urgent need for comprehensive research work in this field. This can be done in a phased manner. Initially it should start with some model mine available in India and then basic data should be generated for mines prone to spontaneous heating. Field testing should be carried out in mine on holidays. Recently CMRI has constructed a mine fire model gallery. It is possible to start reversal experiment in the model gallery itself and then it should extend to mine.

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