UTILIZATION OF BOOSTER FANS IN UNDERGROUND COAL MINES

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Abstract

A booster fan is an underground fan installed in series with a main surface fan and used to boost the air pressure of the ventilation air passing through it. To accomplish this objective, the fan is installed in a permanent stopping and equipped with airlock doors, a monitoring system, and interlocking devices between main and booster fan controls. The stopping and doors are used to prevent flow recirculation, and the monitors to ensure safe operation of the fan.

A booster fan, properly sized and sited, can be used to create safe work conditions and allow the extraction of minerals from areas that would otherwise be uneconomic to mine. In deep and large mines with heavy emissions of air contaminants, the required quantities of air can only be supplied by using high pressure fans. These fans will inevitably induce significant losses of fresh airflow through the stoppings and doors. For well defined ventilation circuits, booster fans can be used to decrease the main fan pressures and reduce the leakage flows. However, this will require a good understanding of the correct ventilation practice, from planning to operation and maintenance of booster fans.

The objective of this study is to investigate the conditions under which booster fans can be used safely and efficiently in underground coal mines. Specifically, the study is directed at (1) collecting reliable information on airway resistances and flow requirements from two large U.S coal mines, (2) collecting fan performance data from one or more existing coal mine where booster fans are used regularly, (3) monitoring the performance of booster fans in a laboratory model and an experimental mine, (4) developing a booster fan selection method to assist the ventilation engineer at the planning stage, and (5) training six M.S. or Ph.D. graduate students in advanced mine ventilation.

Introduction

Coal will continue to be the major source of energy in the U.S. Currently, 69 % of the total coal output is produced from surface mines and the remainder from underground mines. The production from surface mines appears to have reached a plateau. To cope with the growing demand, increased amounts of coal will inevitably come from deep underground mines. In some western U.S. mines, coal is extracted from seams covered with more than 1,000 m of overburden. At these depths coal mining has encountered two new problems: ground control and ventilation. The development of three or more entries has resulted in intersection failures, rib falls, and frequent bumps. These problems have contributed to reductions in the cross-sectional area of main airways, with a consequent increase in resistance to air flow. At the same time, with increased depth, the gas emission and heat flow rates have also increased, requiring larger quantities of fresh air. In some mines, belt air entries have been used to supply additional amounts of air to active workings, but in most cases, high-pressure fans are used to supply these quantities. Higher pressure fans often induce larger losses of fresh air and create unsafe conditions. Booster fans can be used to assist main fans in overcoming these adverse conditions.

The utilization of booster fans started in the United Kingdom in the early 1900's. Indeed, in 1905, Alfred Tonge reported that booster fans were used to ventilate three separate coal seams at the Hulton Colliery. The U.K. Coal Mine Act of 1911 allowed British coal mines to use booster fans, provided that there was a main fan on the surface. As a result, many underground booster fans were installed in coal mines and work conditions improved substantially. This was demonstrated by a drop of fatal explosions from 23 in 1911 to 6 in 1919 (Saxton 1986).

A review of the current literature in mine ventilation shows numerous examples of the utilization of booster fans. The Wearmouth colliery is one of such examples. In this mine, the active workings were at distances of more than seven miles from the access shafts. The ventilation system consisted of two main intake slopes and one return shaft. The air was directed to the workings by means of one surface fan and three booster fans with a combined capacity of 236 m^3/s. One of the booster fans extracted 99 m^3/s of air at 5,000 Pa of pressure (Robinson 1987).

In 1986, Jim Walter Resources Inc. submitted a petition to MSHA to operate an underground booster fan at its No. 7 mine. The plan specified a Jeffrey fan equipped with a 746 kW direct drive motor located in the main intake. The projected fan capacity was 330 m^3/s at 2,000 Pa. The proposal was rejected mainly due to the potential for flow recirculation through the fan. The proposal was revised to eliminate the danger of flow recirculation, the fan capacity decreased to 154 m^3/s at 1,075 Pa (298 kW), gas detectors made available, and resubmitted to MSHA in 1987 (Sartain 1989). Two years later, the proposal was rejected mainly due to lack of expertise in the mining industry to evaluate the performance of these fans.

Utilization of Booster Fans

Currently, booster fans are used in several coal mines located in the United Kingdom, Poland, and Australia (Jobling 2001; Brake 2006).

A booster fan is an underground ventilation device installed in the main airstream (intake or return) to handle the quantity of air circulated by one or more working districts (McPherson 1993). It is installed to operate in series with a main fan and boost the air pressure of the ventilation air passing through it (Figure 1). To accomplish this objective, the fan is installed in a permanent stopping and equipped with airlock doors, interlocking devices between main and booster fan controls, and a monitoring system to assess continuously the operating conditions of the fan.

Before the use of any booster fan is considered, alternate options should be evaluated. Options such as upgrading the main fan, repairing damaged bulkheads, and slashing/widening high resistance airways should be considered first, then the possibility of using booster fans. In existing mines, evaluation of the use of booster fans involves four major steps: planning, fan selection, installation, and commissioning.

Planning

Planning for the use of these fans almost always starts with ventilation surveys and estimation of airflow requirements. This is followed by network modeling and simulation exercises for different ventilation strategies. Optimization procedures such as those developed at the University of California, Berkeley, and the University of Nottingham can be used to this purpose and feasible solutions generated (Calizaya 1987; Moll 1994). Furthermore, these can be used to size fans and predict future requirements. However, the simulation results should be checked against practical constrains such as the need of driving bypass drifts, slashing existing drifts, and installing airlock doors.

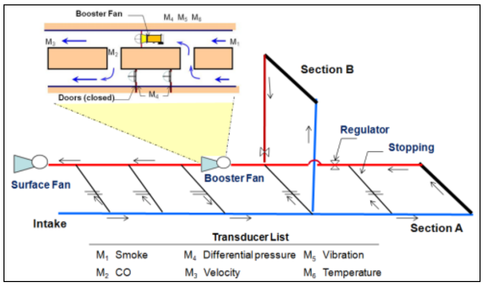

Figure 1. Ventilation Schematic Showing the Location of Main Fans

Fan Selection

Once the fan duties are specified, the next step is to determine the type, size, and number of fans for the system. Here the objective is to select a fan or set of fans that meets the flow requirements and has high efficiency. There are two basic types of booster fan installations: cluster fans and custom built fans (Burrell 1995). Cluster fans consist of several small axial fans installed in series or parallel arrangements. They are reasonably cheap and readily available. They have a common problem, which is their low efficiencies, usually less than 60 %. On the other hand, custom built fans are designed to develop the required pressures at high efficiencies (greater than 80 %) for a wide range of flow rates. They are equipped with inlet and outlet cones, fixed guide vanes, and self closing doors. They can be of axial flow, radial flow, or mixed flow type. To reduce leakage and recirculation, they are installed in concrete bulkheads and equipped with fan condition monitors. Usually, they have higher capital cost than the cluster fans, but reasonably low operating costs for the same fan capacity.

Fan Installation

Following the fan selection, the next task is site preparation and fan installation. This may require the development of a bypass drift, widening of an existing drift, installation of airlock doors, and miscellaneous civil constructions. The drifts should be widened as recommended by the fan manufacturer. They should provide ample space to house the fan assembly, an overhead monorail, mandoors, and fan condition monitoring components. The fan installation usually starts with the construction of concrete foundations. This is followed with the installation of an overhead monorail, the installation of fan housing and the construction of a bulkhead. The job is completed with the installation of airlock doors and a pre-fabricated fixture between the diffuser and the bulkhead.

Fan Initiation

The next task is fan testing and commissioning. Testing involves checking the fan for stability, and running it first at no load (with the airlock doors open), and then at full load (with the doors closed). Parameters such as vibration, bearing temperature, shaft alignment, and blade tip clearance are measured during each test. These values are then compared against standards and pre-established limits. During testing, the following standards are often used: vibration: 0.05 mm/s; motor temperature: 85 ºC; shaft alignment: 0.05 mm; and fan duty: ± 5% of designed values. The fan is commissioned only when the measured parameters are consistently lower than the pre-established limits (Snaith 1998).

Potential Problems

Inadequate booster fan selection or installation introduces potential hazards including an increased likelihood of mine fires and recirculation of contaminants. In the history of utilization of booster fans, two major incidents that claimed lives are commonly reported: the Auchengeich Colliery fire in Scotland (1959), and the Sunshine Mine fire in Idaho (1972).

In the first case, the belt drive on the booster fan caught fire. The fire spread to the roadway timber and claimed the lives of 43 workers. The workers died from carbon monoxide poisoning. Since then, the use of vee-belt drives in underground mines has been severely restricted (Robinson 1989).

In the second case, the mine was ventilated by four booster fans installed in series. According to the U.S. Bureau of Mines, the probable cause of the fire was spontaneous combustion of scrap timber used to backfill worked-out stopes. By the time the fire was detected, the smoke had already filled the main haulage way (3700 level) and the intake raises and active stopes located on lower levels (4000-5200 levels). The fans contributed to the rapid propagation of smoke into the workings inby the fire. Among other factors for this incident were: failure to provide the fans with remote control, failure to monitor the mine atmosphere for carbon monoxide, and delay in starting the evacuation of personnel. As a result, 91 men died of carbon monoxide poisoning (Jarret 1972).

In both cases, new lessons were learned, contributing factors identified, and the existing standards modified so that mistakes such as those illustrated in these examples would not be repeated.

Significance of this Study

This study has the following objectives:

1. To conduct ventilation surveys in two deep and/or extensive U.S. coal mines, and determine the fan duties, airway resistances, and the airflow distribution in the mine. In addition to pressure/ quantity measurements, the surveys will include gas/ dust sampling, and temperature measurements.
2. To conduct ventilation surveys in two existing non-U.S. coal mines where booster fans are used regularly. Plans will be developed to visit at least one of the U.K. Coal Ltd’s Thoresby collieries in North Nottinghamshire, U.K., and the BHP’s West Cliff mine in New South Wales, Australia. Alternatively, Peabody’s North Goonyella mine in Queensland, Australia, will be visited.
3. To install a booster fan system at the Missouri S&T Experimental Mine in Rolla. In addition to a 15 kW fan, the system will include various monitors to measure both environmental factors (carbon monoxide, smoke and air velocity) and fan operating factors (pressure, fan vibration and motor and bearing temperatures). The collected data will be used to determine the effect of these factors on the safe operation of the fan.
4. To conduct air pressure/ quantity surveys at the University of Utah’s coal mine ventilation model. To this purpose, the model will be upgraded to include a booster fan, a “gob” chamber, a set of regulators and a monitoring system. The collected data will be used to determine the critical parameter(s) to avoid unwanted recirculation.
5. To develop a fan selection algorithm for underground coal mines. For a mine of given geometry, with a possible set of fan locations, the algorithm will determine the design parameters for the safe operation of both main and booster fans.
6. To summarize the basic requirements for the safe operation of booster fans. This will include a summary of standards and regulations adopted by other coal mining countries, applicable standards used in U.S. metal/ nonmetal mines,

and rules of good practice for the fail-safe operation of these fans.

7. To train six M.S. or Ph.D. graduate students to the level of advanced mine ventilation.

An overview of three of these objectives is presented below.

Fan Selection Procedure

The procedure applied in this study is the one developed at the University of California, Berkeley. This is an empirical approach which, by using a ventilation simulator, allows optimization of a power consumption function subject to a set of linear relationships between fan pressures and regulator resistances. Here, it is assumed that the ventilation system consists of a network of airways, a number of working areas with fixed airflow requirements, and a set of main fans of unknown pressures.

For a two fan system, one main fan and one booster fan, this procedure can be summarized by the following two routines:

Single Fan System

The process is initiated by assigning a trial pressure to this fan, solving the network for airflow rates and pressure drops, and evaluating the resulting regulator resistances. These resistances are arranged in decreasing order of magnitude and evaluated by applying the following criteria:

- If the smallest resistance is positive, then the fan is oversized. To achieve an improved condition, the trial pressure should be decreased by a fixed amount and the process repeated.
- If the smallest resistance is negative, then the fan pressure is inadequate. This should be increased by a fixed amount and the process repeated to achieve an improved condition.
- If the smallest resistance is equal to zero, then the trial pressure is the lowest fan pressure that minimizes the input power requirement.

In most cases, the solution to the problem can be achieved after three iterations.

Two Fan System

At this stage, the single fan system is modified to include a booster fan. The network is then solved for the best combination of fan pressures. The procedure is initiated by assigning a fixed pressure to the booster fan and varying the main fan pressure for a given range. For every pair of fan pressures the network is solved for flow rates, pressure drops, and a set of regulator resistances. By applying the evaluation criteria described previously, a local optimal solution to the problem can be determined. At this stage, the total power consumed by the two fans can be calculated. The procedure is repeated for other booster fan pressures and a set of local optimal locations determined. These results can then be plotted as pressure-power graphs, and used to determine the global solution to the problem, namely a pair of fan pressures that satisfies the air flow requirements at the workings and minimizes the total power consumption.

For large networks this procedure can be quite time consuming and complex, especially for networks with multiple surface fans. A more robust and efficient approach to these types of problems will be sought in this project.

The University of Utah's Coal Mine Model

A plan view of the current coal mine model is shown in Figure 2. This model consists of 14.6-cm diameter ductwork configured in a common U shaped ventilation system. The intake and return drifts are joined by 5 crosscuts. The first four (A, B, C and D) are kept blocked by interchangeable, perforated gate valves that form leakage paths (stoppings). The last is kept open to represent an active mining section. The sets of perforated gate valves have various hole-sizes and configurations ranging between 0.16–0.64 mm, which corresponds to 1.1–30.6% open area, respectively. This ability to vary the simulated stopping resistance makes it possible to represent various types of stopping materials such as Omega blocks, cinder blocks, Kennedy panels, etc. The system is powered by a 2.5-kW centrifugal blower fan equipped with a variable frequency drive motor. When the fan motor is operated at 60 Hz (3600 rpm), the fan circulates 28.6 m^3/min of air at 1500 Pa of static pressure.

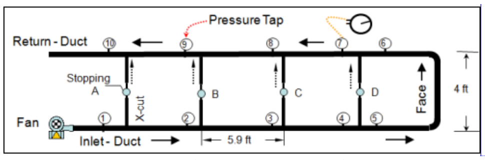

Figure 2. Schematic of the University of Utah Coal Mine Model

A test is conducted by inserting one of the sets of perforated gate valves into the stopping slots, setting the fan motor frequency to a predetermined level, and powering the fan. Once the airflow in the system has stabilized, static and velocity pressures are measured at any number of stations using calibrated manometers and Pitot tubes. A six-point, equal-area traversing method is used to measure velocity pressure readings. The average velocity pressure is then used to calculate flow quantities throughout the system, including leakage and face

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quantities. Stopping resistances are calculated using Atkinson's equation ($R=P/Q^2$).

Table 1 shows the results of an experiment that was carried out using stopping size #1 (30.6% open area). In this case, the fan supplied 28.64 m^3/min of air at 1500 Pa of static pressure, but only 16.65 m^3/min of air reached the face. The reminder (42 %) is short circuited through the stoppings as leakage. Figure 3 shows the leakage flow rates through each of the stoppings. The graph shows that a significant percentage of the leakage is short circuited through the first two stoppings. Similar results were obtained using differing fan settings as well as other stopping sizes.

Table 1. Experiment Results Using Stopping Size #1

Location	Quantity m^3/min	Leakage %	Pressure drop, Pa	Resistance Ns^2/m^8
A	3.28	0.27	1000.0	3.35E+05
B	2.99	0.25	837.5	3.36E+05
C	2.87	0.24	700.0	3.06E+05
D	2.85	0.24	600.0	2.66E+05
Face	16.65		612.5	7.95E+03
Fan duty: Quantity: 28.64 m^3/min; Static pressure: 1500 Pa				

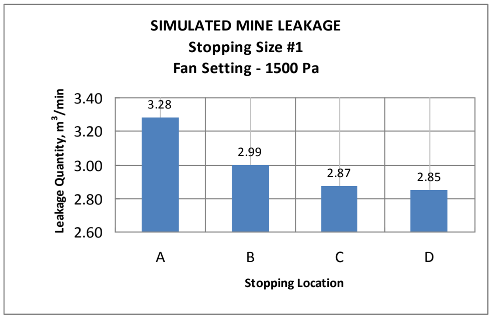

Figure 3. Example of Leakage Model Output

For the booster fan study, this model will be upgraded to include a booster fan, a gas injection system, and a set of ventilation monitors (Figure 4). A 2.0 kW booster fan will be installed in line with the main fan. This with be equipped with bypass ductwork and flow control valves. Carbon dioxide will be used to simulate the gas generated at the face. The model will be used to investigate the airflow through simulated mine openings for different fan and regulator settings. The main objective of this investigation is to determine the conditions under which flow recirculation can be avoided. This model will also be used to calibrate CFD-based numerical models. The CFD models will be used to conduct parametric studies and to determine gas flow patterns and energy losses for various fan settings.

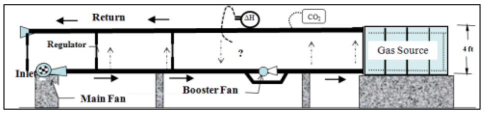

Figure 4. Schematic of the Utah's Booster Fan Model

The Missouri S&T Experimental Mine

The Missouri S&T Experimental Mine is an underground limestone and dolomite mine located just outside Rolla, Missouri. The mine (Figure 5) is accessed by two adits and has three raises to the surface along with the primary ventilation shaft. The two mine portals both have ventilation doors as indicated. Currently, ventilation is provided by a 1.2-m diameter Joy axial vane fan and 30 kW motor set blowing approximately 23.6 m^3/s of airflow at 1,000 Pa of static pressure to the underground workings. Currently there is no set ventilation mode for the experimental mine. Kennedy panel stoppings are set to direct the airflow as needed. Activities are undertaken throughout the workings and working places can be simulated at many locations.

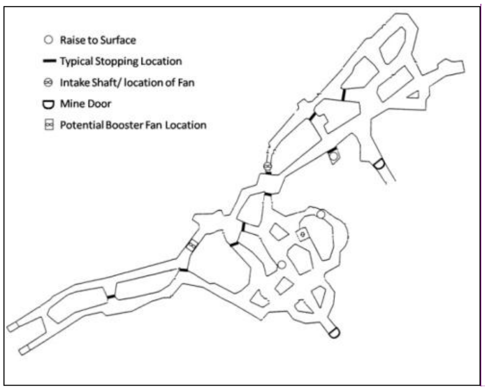

Figure 5. The Missouri S&T Experimental Mine Map

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The experimental mine is used mainly as a teaching laboratory for classes such as surveying, ventilation, drilling and blasting, and mine health and safety. The mine also hosts an annual mine rescue competition every September that draws some 15 teams from around the U.S. There are currently no research projects located in the underground workings of the experimental mine. However there are some projects located on the surface and in another underground mine located nearby. The mine is equipped with compressed air, water, and 110 V AC power throughout, as well as being well lit. There is a small shop that is equipped with a variety of tools needed for minor repairs on equipment. A variety of small carts and a single, skid-steer loader are available for transport of materials underground.

The initial plans for the mine in relation to this project are the upgrade of the main fan as well as the installation of two booster fans in the underground workings. The booster fans will be installed in bulkheads in a flexible manner so location can be varied during the project. Electronic monitoring systems will be installed to monitor the differential pressures across key stoppings and bulkheads as well as the flow quantity through mine airways. This data will be logged by computer and models will be created to determine optimal placement of booster fans within mine ventilation circuits.

Missouri S&T researchers are also currently working on comprehensive literature reviews of international practices regarding booster fans. There are numerous coal mines globally that rely on booster fans to ensure adequate ventilation. With this literature review the researchers hope to establish a baseline for the beginning of our research. The current focus is on Australia and England, where there are currently several coal mines using booster fans. Missouri S&T researchers are also working in conjunction with University of Utah researchers in locating U.S. coal mines that would be willing to allow researchers into their mines to conduct pressure and quantity surveys so that models in VNetPC or Ventsim can be created, allowing the researchers to determine the optimal placement for booster fans.

Conclusions and Discussions

The University of Utah and the Missouri University of S&T have accepted the unique challenge of investigating the conditions under which booster fans can be used in U.S. underground coal mines. This study has the following objectives:

- To conduct ventilation studies in two deep and/or extensive U.S. coal mines, formulate numerical models, and determine their future ventilation requirements.
- To conduct ventilation surveys in two non-U.S. coal mines where booster fans are used regularly.
- To conduct ventilation studies on the utilization of booster fans at the Missouri University of S&T Experimental Mine and at the University of Utah's coal mine model.
- To develop an efficient booster fan selection program.

In ventilation planning, flow control devices such as stoppings, overcasts, and doors are used to direct the fresh air to active workings and to reduce leakage. These are characterized by a parameter: the leakage path resistance. The magnitude of this parameter varies with on a number of factors including the type of construction materials used, workmanship and maintenance. These factors will be investigated through field measurements, laboratory models and numerical simulators.

Currently, there is no single booster fan selection method that can readily be used by ventilation engineers. Several procedures have been formulated for this purpose. However, these are inefficient, and time consuming. A new fan selection algorithm to produce recirculation-free ventilation designs will be developed. This will enable U.S. coal mine operators to develop ventilation designs to extract coal seams from depths greater than 1,000 m below surface.

Acknowledgement

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