UNDERGROUND BOOSTER FAN PLACEMENT STRATEGIES

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ABSTRACT

Booster fans play an important role in assisting main fans by boosting the air pressure of the ventilation air passing through it. The correct placement of underground booster fans in a mine is a critical decision since it not only influences the mine's operational capacity in terms of costs and efficiency, but also affects safety and environmental conditions. There are many booster fan installations around mines that are inappropriate, in some cases resulting in system failure (fan stall) or in a major negative impact on mine production. Inadequate booster fan placement has resulted, in some cases, in extensive air leakage which has compromised the economics of the operation and, in other cases, in recirculation of contaminants which has seriously compromised safety. This paper provides guidelines for proper design and siting of booster fans underground, to not only achieve an economic ventilation system but to create safe work conditions and efficient atmospheric conditions. Procedures for the planning, installation, operation and maintenance of booster fans are also presented. A case study illustrating the design and siting of a major booster fan installation in a potash mine, supported by computational fluid dynamics analysis, is presented.

KEYWORDS

Booster fans, Fan placement, Fan installation, Mine ventilation

INTRODUCTION

In large underground operations with complex ventilation networks offering high resistances, the never ending increased required quantities of air can almost only be supplied through use of high pressure main fan systems. These fans may, in effect, induce significant leakage losses in the system, having a negative impact on safety performance. In such cases, booster fans can be designed to decrease the main fan pressures and reduce the leakage flows, improve system efficiency and reduce costs. In well designed systems, booster fans can thus be used to redistribute the airflow and assist the main surface fans.

When the pressure supplied by the main fans is insufficient to meet the ventilation circuit pressure requirements, booster fans are placed in strategic locations where pressure boosting is essential. Booster fans are typically sited in sections of the circuit offering high ventilation resistance and requiring this form of ventilating air motivation. Booster fans are thus required when the mine expands, and so the resistance of the ventilation network, and the primary fans no longer can supply the required pressure and flow.

From the above discussion, a booster fan can be defined as a fan operating in series with a primary fan, its operation being essential in maintaining the overall mine flow.

Different methodologies exist to determine fan duties, however they do not check the leakage or recirculation for the ventilation circuit. Network modelling using ventilation software and numerical modelling analysis (computational fluid dynamics) represent important tools for design verification and for assessing the effect of booster fans on system efficiency, system leakage and system recirculation.

A case study is presented to demonstrate the design and siting of a major booster fan installation in a potash mine, supported by computational fluid dynamics analysis, is presented. The fan locations were sited to optimize four constraints: minimize shock loss (inlet and outlet); ensure even loading on fan inlets; minimize sound exposures, especially in the shaft cross cut; and ensure exit air stream velocities did not pose any threat to traffic by way of particle projection/entrainment.

BOOSTER FAN APPLICATIONS

Booster fans, when installed in primary airways, are used to work in tandem with the primary fans, influencing the airflow and pressures throughout the ventilation network.

Booster fans are more commonly used to improve or augment the ventilation in a segment of the mine offering high resistance. Booster fans may also be used to influence specific production levels or mining blocks, designed to provide flow requirements for the production equipment fleet.

Booster fans, when appropriately spaced, are effective in reducing the differential pressure across intakes and returns in a mine thus reducing air leakage or recirculation issues. Booster fans may thus be used to induce controlled recirculation in sections of a circuit; in such case sizing and placement of the fan are very critical, since incorrect siting of a booster fan could result in uncontrolled recirculation and unsafe conditions.

Booster fans are also applicable in hot underground environments by improving the working environment through increased air velocities.

ISSUES WITH BOOSTER FANS

It is not uncommon to find mining operations using booster fans that are unsuitable for the intended application. The placement of a booster fan in an airway may result in loss of pressure and reduction in airflow in other airways, and in certain circumstances, a complete of cessation of flow. In other cases, booster fans, when used to improve ventilation in a segment of the mine offering high resistance, may, depending on its location and generated pressure, cause uncontrollable recirculation or uncontainable air leakage.

The siting of the booster fan and the design of its pressure are thus critical in ensuring its proper operation. This requires precise engineering assessment to ensure that airflow in other sections of the mine is not compromised.

In order to avoid air leakage or recirculation, the booster fan should be sited at a location at which the pressure difference between the intake airway and the return airway is equal to the booster fan pressure. If the fan is sited upstream of this point, the pressure in the return airway will become higher than that of the intake airway. Under such situation, if there is a leakage path, it may result in recirculation. If the fan is sited downstream of this point, the pressure in the intake airway will become higher than that of the return airway. In such case leakage flow will occur across any existing leakage path.

BOOSTER FAN SIZING AND SITING

As previously discussed, the siting and size of the booster fan will affect the ventilation system efficiency and air leakage or air recirculation.

Sizing of booster fans require a number of steps to be followed, presented below. Each process step of the methodology is illustrated in Figure 1. This procedure is an adaptation of a ventilation planning methodology developed by Clarke and De Souza (2019).

step 1 - first, the components of the mine development and production plan must be analysed to define ventilation requirements for all areas of the mine. In this each level is defined as per planned activities, as either inactive, waste development, ore development, ore production, or backfill.

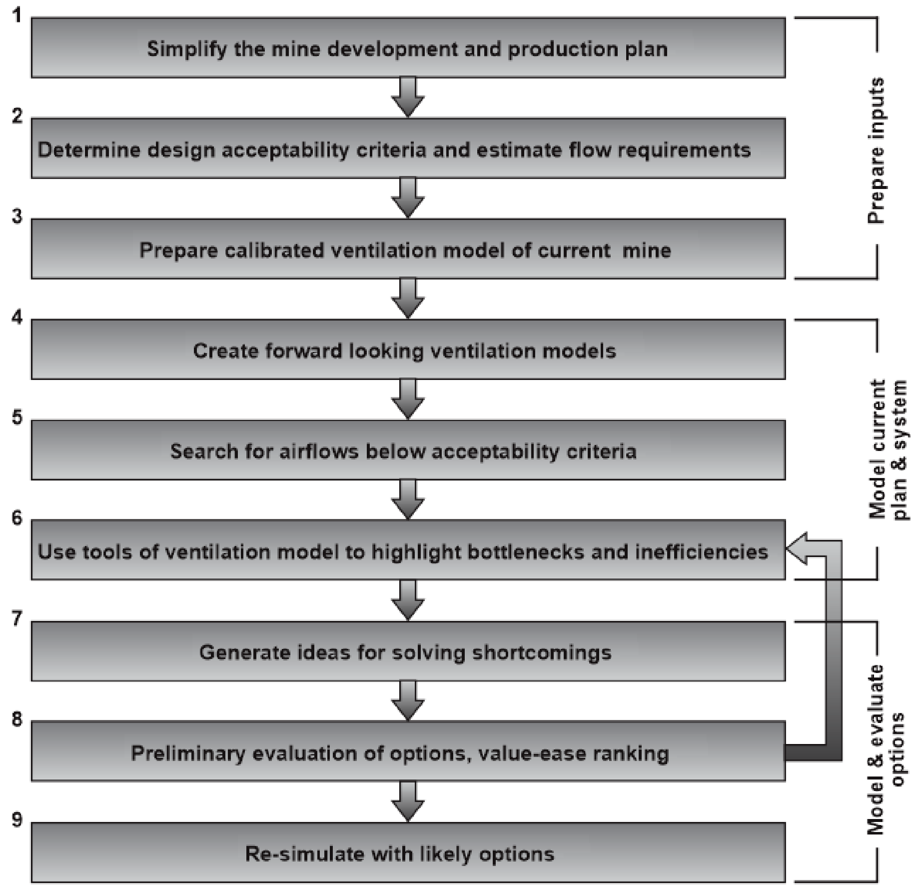

Figure 1. Methodology for booster fan sizing and selection

step 2 - ventilation design criteria are then determined based on company policy, mine parameters, industry best practice, environmental parameters, and regulatory requirements. These design criteria are then applied to the activity plan to estimate the airflow requirements for each level and for the mine.

step 3 - a validated and calibrated ventilation model using data from field surveys is built to permit accurate simulations of planned mine development and production activities.

step 4 - accurate ventilation models of each future period of the mine production plans are created.

step 5 - the designer then searches for working areas where the airflow modelled is less than the requirement as per the design acceptability criteria (step 2) and searches for constraints and recirculation or leakages in primary ventilation circuits. Bottlenecks and inefficiencies are also investigated, including areas with excessive air velocities, areas where high shock losses occur, restricted fans, etc.

step 6 - solutions for solving shortcomings are then generated to bring all airway branches up to the design criteria. This is where the need for a booster fan may be considered. The effect of booster fan sizing and placement on system pressures, system leakages, air recirculation and system efficiency is evaluated. Other general solutions include sealing unwanted air leakage and eliminating recirculation; regulating airflows from an over-supplied to an under-supplied area; increasing primary fan power; decreasing system resistance (slash drifts or use parallel airways) to increase operating point airflow volume.

step 7 - rank the various solutions in terms of value and ease. The ranking will indicate which solutions deserve the effort to develop. The solutions that are both easy to implement and have a high value are the first to receive attention. Next those that are high-ease but low-value and low-ease but high value are pitted against one another for attention. Solutions that appear to be low value and difficult to implement are put aside right away.

step 8 - with all the solutions collected and the best options identified the framework moves forward to simulate these in great detail for each period of the mine plan. This is where the booster fan is optimized, sized and sited. At this stage, there should be a few projects that meet the design criteria. An economic analysis of acceptable options is performed, preliminary capital budgets with operating costs are created, schedules implemented and critical path work identified.

step 9 - the best option is selected and design optimization of the mine ventilation plan with optimum booster fan sizing and siting are completed. Design support tools, such as computational fluid dynamics analysis, are applied to optimize the booster fan installation design and siting.

Sizing of the booster fans should be done in total pressure. The system static resistance pressure, which corresponds to the static pressure across the fan bulkhead, is first determined, and the fan assemblage losses (screen, inlet bell, silencers, etc.) are then added. The fan velocity and velocity pressure, including cone losses, are determined based on the fan annulus area.

INSTALLATION CONSIDERATIONS

Booster fans are installed on a bulkhead, and with an airlock to allow passage through the fan drift, illustrated in Figure 2. The fan chamber must be carefully designed to meet the recommended distances between fans and distances from the walls and back. Slashing of the chamber walls should be completed to minimize shock losses (gradual expansion and contraction) as the air enters and exits the chamber. Fan components should include an inlet bell, a cone and protective screens on both ends. Inlet and outlet silencers are commonly used for noise reduction. Booster fans are more commonly installed as a single fan or as parallel fans. Series or series-parallel fan configurations are also applicable depending on pressure and flow requirements. Fans installed in parallel also require the use of control dampers.

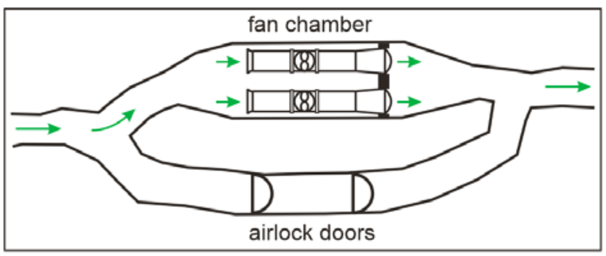

Figure 2. Booster fan installation schematic

The aerodynamic conditions at the inlet and outlet of the fans must be carefully considered to eliminate the detrimental effects of turbulence, eddies and vortices. If the air entering the fan has an uneven flow distribution, a difference in volume loading of the individual blades will cause cyclical bending of the blades, leading to fatigue failure associated with stress loading and unloading cycles of the blades.

The siting of booster fans is thus important to prevent uneven airflow volume loading of the blades. There should be no obstructions in close proximity of the fan inlet such that all blades are evenly loaded across the fan inlet area. The booster fans should be located along the drift where air streamlines form a full flow condition across the airway section. When installed in parallel, a minimum distance of one fan diameter should be observed between the fans and between each fan and the walls and back.

COST CONSIDERATIONS

Booster fans may become a more attractive and economically viable solution when the required increase in airflow cannot be achieved economically by upgrading the main fans.

Booster fans, when properly designed, may reduce the required main fan pressure and consequently reduce overall ventilation costs and may also decrease system leakages, resulting in increases in ventilation system efficiency.

MANAGEMENT AND CONTROL CONSIDERATIONS

In many complex mine ventilation networks, where a multitude of booster fans are used to control the direction and magnitude of flow, their energy usage normally well exceeds the overall mine energy consumption. Careful management of booster fans is thus essential in minimizing operating costs.

Management systems can be applied for optimizing the operating performance of booster fans, maximize safety and minimize risks. Structured plans, procedures and processes on the day-to-day operation of booster fans can be incorporated into the ventilation program. The application of booster fan management programs consists of audit, verification, and corrective action procedures to ensure adherence to standards, or to return to compliance and safety standards when an upset condition arises. Proper implementation of a management program will result in significant benefits including increased operational effectiveness, increased safety, improved engineering efficiency, reduced fan maintenance costs and reduced energy costs. Applications of mine ventilation management systems are described by De Souza (2017).

A monitoring system is a basic requirement in the operation of booster fans. It is recommended that booster fans be under PLC control and fitted with diagnostics and control instrumentation. Monitoring data - including on/off local indication, motor amps, rpm, airflow rates, fan bulkhead differential static pressures - can be transmitted to the mine central control room for remote monitoring. Ideally, booster fans should be fitted with variable speed drives, which allows the use of soft start.

Technology can also be readily applied to allow remote control of the installed fan to suit a variety of operating points by way of changing the VFD setpoint, or even remotely turning the fan on or off as required. Feedback loops can be used in conjunction with instrumentation to have the system adjust automatically to upset conditions or to maintain flows in places where ambient conditions can drive changes in required fan setpoints.

CASE STUDY

An engineering design was conducted for determining the optimum location of two underground booster fan stations designed to draw air coming out of a fresh air service shaft in a potash mine (Penner, 2015). The analysis also aimed at minimizing sound exposures in the immediate vicinity to the shaft station given the fan's proximity to the shaft area where all workers will be entering and leaving the mine.

The booster fan drifts were cut immediately adjacent to the main shaft cross cut and were excavated to be 14 m wide by 3.7 m tall to reduce air velocities to as low as reasonably practicable, and where possible, corners in the excavations were cut at 45 degrees to reduce shock losses. Figure 3 presents a schematic of the booster fan installations.

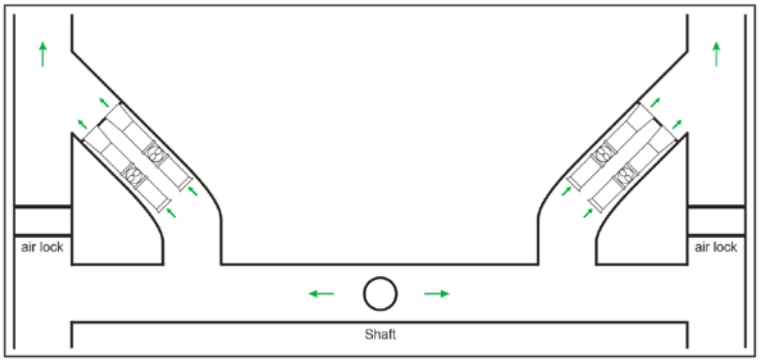

Figure 3. Booster fan installation schematic (AirFinders Inc., 2013)

A computational fluid dynamics (CFD) analysis was completed on the booster fan drift using the as-built dimensions. Projected airstream velocity profiles were analyzed along the drifts for several installation locations as outlined in Figure 4. The volumetric flow rate through each fan drift was 142 m^3/s. The investigation concluded that the fans should be installed on the inboard side of the corner at location B (Figure 4), as shown in Figure 5. This location was concluded to be the best based on the prediction of non-biased inlet airstream velocity profiles, as well as the projected outlet airstream velocity profile that shows the best (least) interaction with the downstream walls. As well this location exhibited the lowest velocity distortion values in the CFD model.

Due to the proximity of the fan installations to the service shaft station area, a focus was put on sound attenuation when designing the underground booster fans. Testing was completed to estimate the required silencing prior to fan design. Using the sound level samples obtained at the planned booster fan installation, a contour map was modeled for the shaft area (Figure 6). Based on the sample data and drift geometry, and if the silencer could reduce sound at the fan to 95 dBA, a minimum fan offset of 60 meters would be required to achieve a sound level less than 85 dBA to comply with regulatory requirements. Downstream of the fans, estimated sound levels showed that hearing protection would still be required by law through the intersection where the airstream turns into the main travel way. This is a short distance, and therefore represents a small area of exposure.

In the case study, reconciling the airflow and sound considerations, location B was recommended for the fan installations. Location B is the optimal location given the inlet and outlet airstream profiles, and is sufficiently far away from the shaft area to allow for sound levels to drop below levels requiring hearing protection.

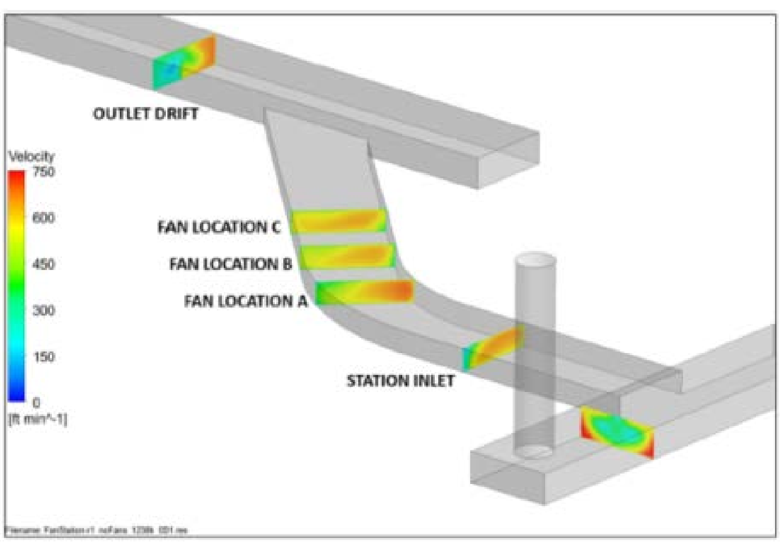

Figure 4. CFD analysis installation outline

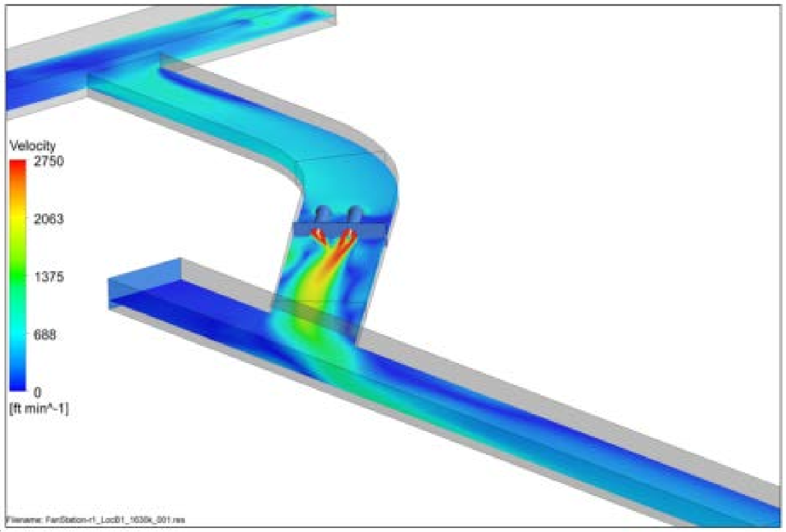

Figure 5. Optimized booster fan installation siting

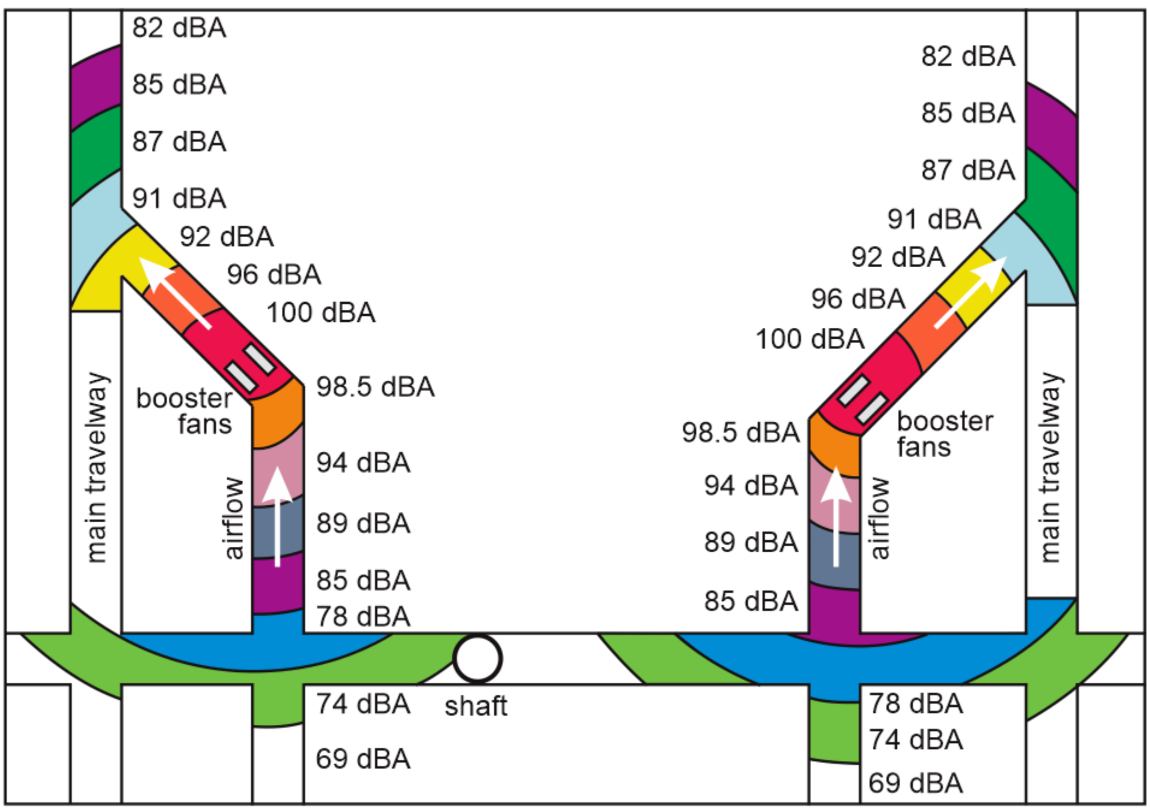

Figure 6. Estimated dBA contour map at the shaft area

CONCLUSIONS

This paper has introduced procedures for booster fan selection and siting than can be readily used by ventilation engineers. Proper design and siting will result in significant benefits including increased operational effectiveness, increased safety, reduced fan maintenance costs and reduced energy costs. A case study was also presented to demonstrate the process for siting fresh air booster fan installations in a potash mine.

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