The Mystery of the Ventilation Raises

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In two different operating mines, operational issues associated with the proper functioning of their primary ventilation exhaust raises have prevented the mines from operating safely and within their target production rates. In one mine, the primary exhaust fan operation would become unstable and the fan would stall, resulting in structural fatigue damage and ultimately the destruction of its blades. This occurrence repeated approximately every 6 months. Naturally, the frequent unavailability of the main exhaust raise was unacceptable from an operational point of view. In the second mine the raise is ventilated by a 1490 kW surface exhaust fan. In one instance the raise airflow volume dropped substantially, seriously compromising the mine exhaust capacity. Extensive inspections of the fan did not show any fan operational issues, including damage to fan ductwork, vibration, noise or structural damage. This paper will present how detailed on-site engineering assessments unlocked the mysteries of the ventilation raises, how solutions were derived from the investigations and which procedural remedial action plans were devised and recommended. The engineering solutions were implemented by both mines to successfully restore the raise ventilation operations, thus permitting the mines to safely resume production activities.

Introduction

The continuous operation of a well-designed and managed ventilation system is vital to mine production activities and to the health and safety of mine personnel. The mine ventilation system must be continuously and stringently managed to ensure the system meets all regulatory requirements and company policies and cares for the health and safety of all personnel working in the mine.

The mine ventilation system is a continuously changing and evolving system; upset conditions will occasionally occur but should be promptly resolved in order for the system to function properly and according to design.

Those managing the mine ventilation system must have fundamental engineering training in the art of ventilation and have a good comprehension and control of the mine ventilation network. Ventilation management by untrained and inexperienced personnel may result in serious consequences when the system becomes ineffective.

Ventilation personnel must be able to, on a daily basis, evaluate the mine ventilation system, determine and locate any problems, understand the causes of each problem, find a solution, and promptly and efficiently correct those problems.

Two case studies are presented to demonstrate how detailed on-site engineering assessments unlocked the mysteries of two ventilation exhaust raises, how solutions were derived from the investigations and how simple, low cost, engineering solutions were implemented to successfully resolve the issues. The raise ventilation operations were returned to compliance, permitting the mines to safely resume production activities.

The mystery of the exhaust booster fan stall

In an underground hard rock mine, a main exhaust raise serves the lower production section of the mine, exhausting spent air directly to the surface.

The raise was Alimak driven, 2.13 m x 2.13 m in size and 609.6 m long.

The raise is served by an underground booster fan installed in a bulkhead. The fan diameter is 1.372 m and the hub diameter is 0.686 m. The fan has a 186 kW motor, running at 1780 rpm. The fan is fitted with an inlet bell and screen, but has no cone. The fan was operating at a blade setting of 17 degrees. The fan curve is shown in Figure 1.

During operation, the primary exhaust fan would become unstable resulting in fan stall, structural fatigue damage and ultimately the destruction of its blades. This fan failure occurrence repeated approximately every 6 months.

The frequent unavailability of this primary exhaust raise was unacceptable from an operational point of view, preventing the mine from operating safely and from meeting its production schedule.

Mine personnel did extensive work assessing the fan structural installation, including foundation and bulkhead integrity, fan component (including flange, bell, casing, hub) damage, shaft misalignment, blade fatigue, blade pitting, individual fan blade setting, blade tip to casing clearance, motor condition, power source stability, etc.. Manufacturing quality control of the fan blades was also tested by the supplier. No issues could be found; mine management were puzzled with the regular fan failure.

Mine personnel also inspected the raise but did not find any structural issues (sloughing, wall convergence, etc.) which would have increased the resistance of the raise.

An engineering assessment was conducted by the author. The assessment consisted of an audit, verification and development of corrective action procedures. The audit process included detailed inspections of the raise and fan, and pressure and flow surveys of the affected area. The verification process consisted of an assessment of the information collected during the audit in order to verify why an upset condition (fan failure) endured over prolonged periods. The corrective process consisted of the development of engineering action plans and corresponding directives to be launched to return the raise operation to compliance and safety standards. Details of the program implementation are described below.

Psychrometric surveys (barometric pressure, dry and wet bulb temperatures) indicated the air entering the raise to be under full saturation conditions.

Based on pressure and flow surveys, the raise static resistance was estimated at 0.94 $N.s^2/m^8$, including shock losses.

A ventilation survey was conducted at the fan, and the fan flow was measured at 37.76 m^3/s. The fan total pressure, including assemblage shock losses, was determined at 2.06 kPa. The exhaust fan operating point, A, is shown in Figure 1. The fan efficiency is 75% and the brake power 104 kW. According to Figure 1, the fan operating point seems to be adequate.

The question remained, why was the fan repeatedly failing?

When saturated air is exhausted in an upcast raise, as the saturated air rises in the raise, the barometric pressure decreases and consequently the temperature of the air decreases. This results in water being condensed out of the air. The water condenses as very small droplets which give the air a foggy appearance. As the air rises more water condenses onto these small droplets and they gradually grow to larger drops. Under such circumstances, the fan pressure will increase over a period of time while the airflow rate decreases over the same period. This phenomenon is named water blanketing. If the air travels up the raise at much less than 8 m/s, the drops will fall down, if the air is travelling much faster than 8 m/s, they will be carried up the raise. If the air velocity is such that drops of certain sizes are suspended in the air or move up or down the raise, the obstruction they create to airflow is sometimes increased to such an extent that a very considerable increase in raise resistance results. The increase in resistance pressure may adversely affect the fans serving the raise [1, 2].

The most dangerous air velocity, called critical velocity, is about 8 m/s. From the conducted survey, the air velocity in the raise was estimated at 8.29 m/s. It seems that it was taking approximately 6 months for water blanketing associated resistance to increase to the point of fan stall.

With the unlocking of the mystery of the exhaust raise, a control solution to fan stall was developed.

The first step was to install a cone in the fan. A 1.83 m outlet diameter, 1.24 m long cone was installed. The fan velocity pressure, including loss, was reduced to 0.37 kPa from 0.70 kPa (no cone). The fan total pressure, including assemblage shock losses, was determined at 1.84 Pa and the fan flow was estimated at 39.17 m3/s. The resulting fan operating point, B, is shown in Figure 1. The fan efficiency is 70% and the brake power 103 kW.

The operating point is now much lower on the fan curve, however the air velocity in the raise (8.6 m/s) is still within the critical air velocity range.

The next step of the investigation was to change the fan blade setting in order to increase the fan flow and the raise air velocity. The fan blade angle was changed to 23 degrees, to operate at a flow of 47.2 m^3/s and raise air velocity of 10.4 m/s.

With the new blade setting, the fan total pressure increased to 2.68 kPa and the brake power to 162 kW, with the fan operating at 78% efficiency. The resulting fan operating point, C, is shown in Figure 1.

With simple, low cost, procedural remedial actions, the raise exhaust capacity was increased and the fan continued to operate without any further issues, thus permitting the mine to safely resume production activities.

This case shows how the mystery of the fan stall was unlocked and solved using simple, cost effective engineering solutions.

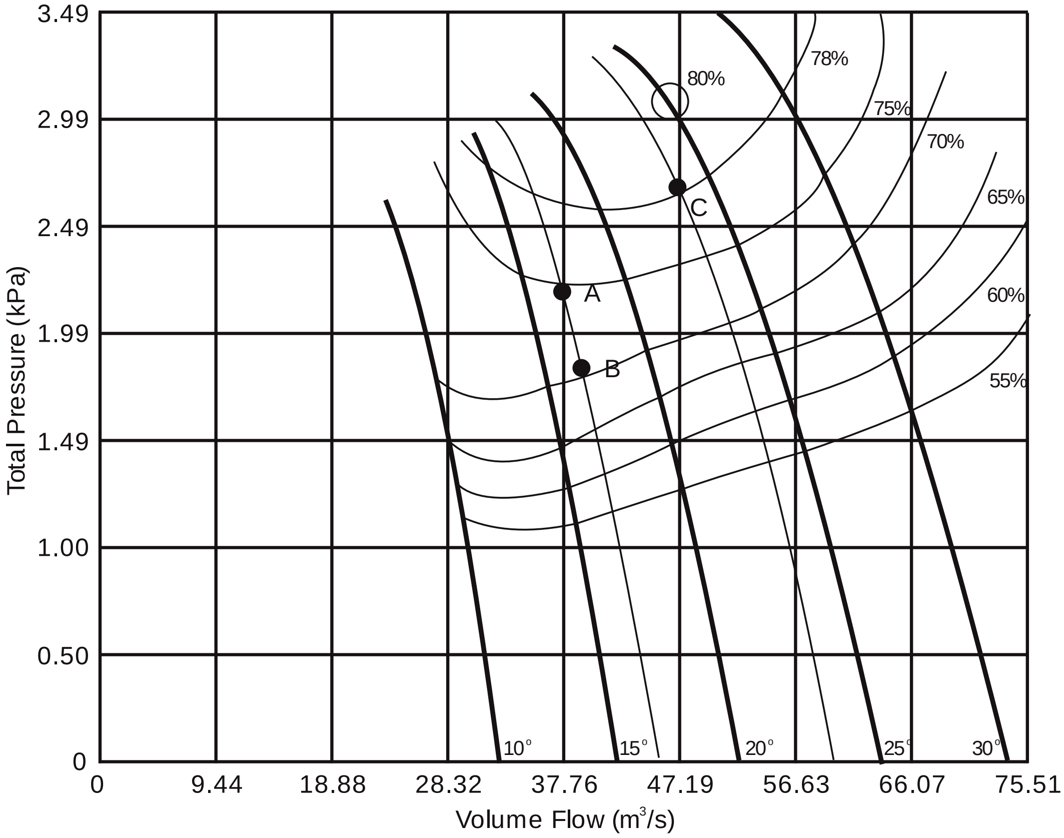

Figure 1: Exhaust Booster Fan Operating Points.

The mystery of the exhaust surface fan reduction in flow capacity

In an underground hard rock mine, a main exhaust raise serves the upper production section of the mine. The raise receives spent air from various levels and from an internal ramp servicing the lower levels (Figure 2).

The raise was Alimak driven and slashed to a 5.8 m diameter, 1,177 m long airway. The raise was driven in several sections and connects to 13 levels. The overall length of the raise, including equivalent lengths at the raise transfers, is 1,304 m.

The raise is served by a 3.76 m diameter surface fan. The hub diameter is 2.5 m. The fan has a 1490 kW motor, running at 715 rpm. The fan operates at a blade setting of 0. The fan curve is shown in Figure 3.

During normal production activities, workers reported a drastic reduction in ramp flows, by more than 50%. The unavailability of the ramp, normally used as a main haulageway to transfer ore from the lower production levels, seriously compromised the mine operation.

Extensive inspections of the surface fan were conducted by mine personnel, and the fan and fan assemblage did not show any fan operational issues, including damage to fan ductwork, vibration, noise or structural damage. A decreased in fan flow of 96 m^3/s was noted by mine personnel, even though the amperage draw was relatively unchanged. Mine personnel were perplexed and could not understand the cause for the reduction in fan flow.

An engineering assessment was conducted by the author. The assessment consisted of a detailed inspection of the fan and of the entire section of the raise. Pressure and flow surveys were conducted, and amperage and vibration readings were taken to determine the fan operating conditions. Each section of the raise was visually inspected to quantify any changes in airway physical characteristics affecting the system performance. Details of the engineering assessment and of the implementation of corrective actions are described below.

The raise resistance was determined and the expected fan operating point, under normal conditions, was estimated at 401.2 m^3/s and 2.9 kPa total pressure. The fan efficiency was determined 90% and the brake power at 1,292 kW. The exhaust fan operating point, A, is shown in Figure 3. This estimate matched very well with historical fan surveys conducted at the mine.

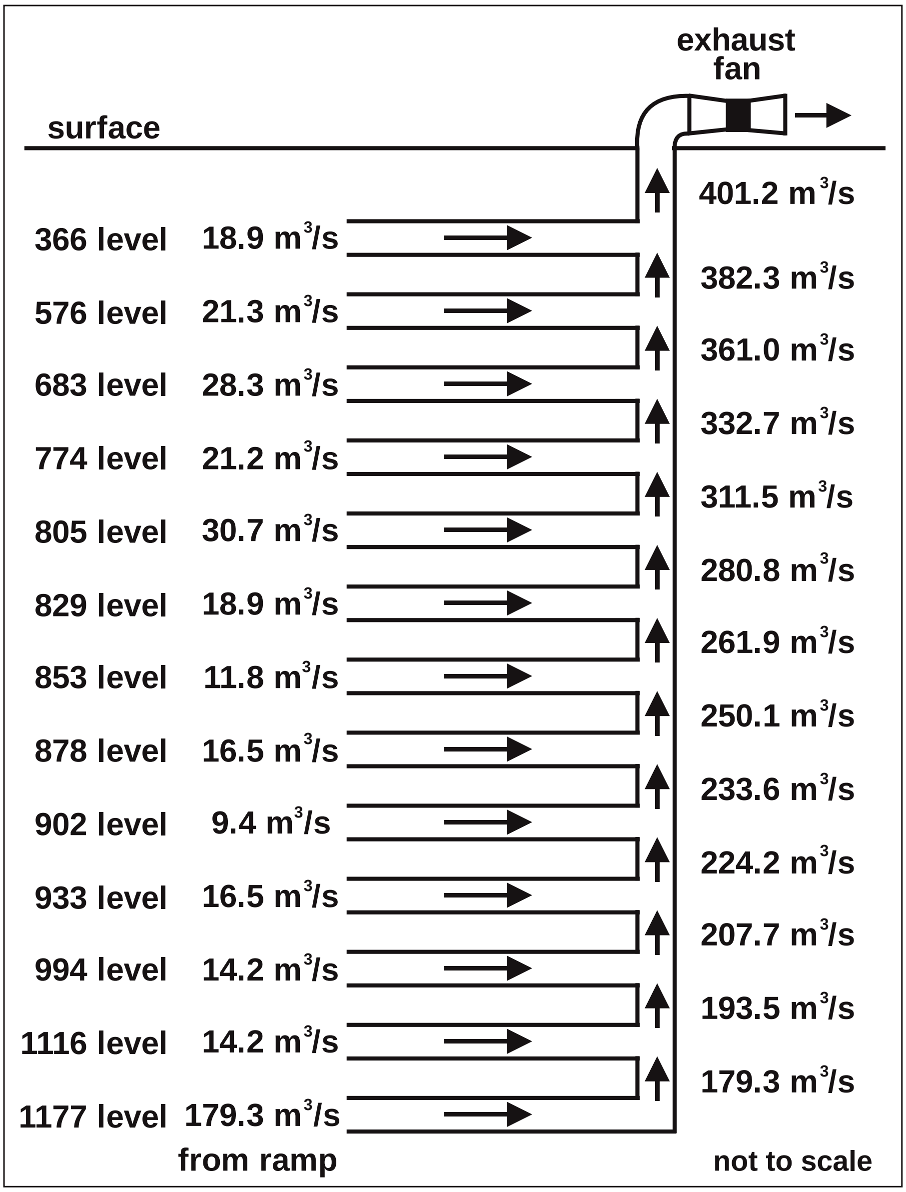

Figure 2: Simplified schematic of exhaust raise.

A ventilation survey was conducted at the fan, and the fan flow was measured at 305.4 m^3/s. The fan total pressure, including assemblage shock losses, was determined at 3.62 kPa. The brake power was estimated at 1316 kW. The exhaust fan new operating point, B, is shown in Figure 3.

It was clear that the raise resistance had increased to a point where the fan was operating at a condition close to stall (Figure 3).

The combined major drop in flow and increase in pressure resulted in no substantial increase in power draw, as noted by mine personnel.

Workers were investigating the fan, when instead they should have been checking the raise. A major production blast had been conducted in a stope in close proximity to the raise. Upon close inspection of the raise, a major ground fall was found in one of the raise transfers, as a result of the blast, restricting the airway and creating the noted increase in raise resistance. Cleanup and rehabilitation of the affected raise transfer were promptly completed and the fan operation restored to its normal.

The mystery of the fan flow reduction was unlocked; although it should have been easily understood by a knowledgeable ventilation engineer and the issue promptly resolved. Have mine personnel had a good understanding of fundamental ventilation concepts, they would have clearly identified the cause of the problem (increase in resistance), promptly located the problem (raise and not fan) and without delay restored the upset condition (clean up raise).

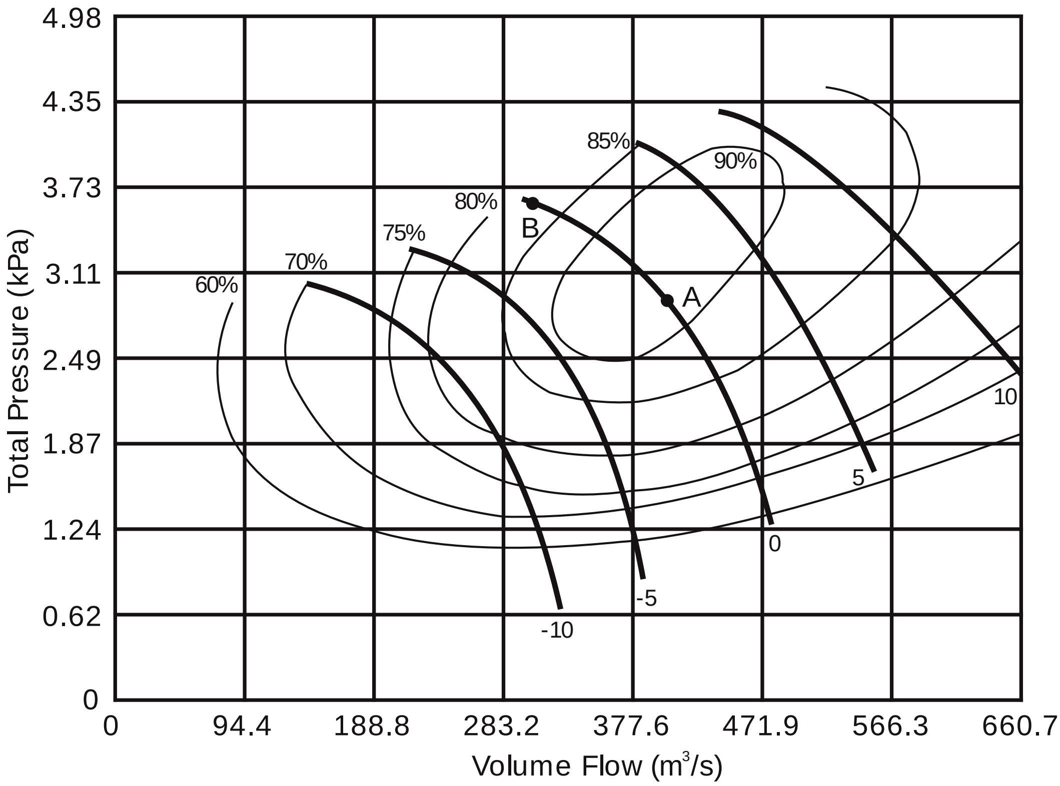

Figure 3: Exhaust surface fan curve.

Conclusions

When an upset condition occurs in a mine ventilation network, an iterative management program should be devised and implemented to permit the operator to efficiently and consistently audit the mine ventilation system. The iterative management program is a three-phase assessment program consisting of an audit, a verification and the development of corrective action procedures, and used to ensure the mine ventilation system operates within compliance standards.

The audit typically includes detailed inspections of all components and appliances, pressure and flow surveys of the network and air quality surveys. Verification programs are used to assess the information collected from the audit in order to identify the causes of the upset condition. If the verification process indicates the system not to be in compliance, then action plans and ventilation directives are initiated to restore the system to compliance. Action plans and corresponding directives are then devised and directly launched to restore the system to compliance.

Two case studies were presented to demonstrate how detailed on-site engineering assessments, supported by well devised management programs, can be used to successfully restore the mine ventilation operations to conformity. The case studies also demonstrated the importance of having well trained and experienced personnel managing the ventilation system in order to be able to properly resolve an upset condition.

References

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[2] Burrows, J., Hemp, R., Holding, W. and Stroh, R.M. (1989) Environmental Engineering in South African Mines. Mine Ventilation Society of South Africa. pp. 987.