

# Design and operational aspects in the use of booster, circuit and auxiliary fan systems

D.J. Brake & C.A. Nixon

*Mine Ventilation Australia, Brisbane, Australia*

**ABSTRACT:** Whilst there have been relatively few innovations in the nature or application of main surface fans in the past 20 years in Australia, there have been a significant number of notable changes in the size, type and application of booster and auxiliary fans. In metalliferous mines, these changes relate to factors such as: increased development size, changes in mining methods brought about by the use of remote and teleremote equipment, the use of air-conditioned cabins, new developments in refuge chambers, significant increases in the use of mine refrigeration and the extraction of both “thinner” orebodies (lower tonnes per vertical meter) and massive low-grade orebodies (caving methods) and overall greater depths. In coal mines, these relate to increased length and width of longwall panels, much higher extraction rates, more effective gas pre- and post-drainage, longer main intakes and returns and changes in legislation. In both coal and hardrock, the use of more and/or much larger diesel engines and changes in the philosophy of egress are also impacting on the use of circuit and booster fans. This paper describes the factors that are influencing new applications for auxiliary and booster fans, the ways in which these fans are being used and some of the problems that have been experienced in the use of booster, circuit and auxiliary fans.

## 1 INTRODUCTION AND DEFINITIONS

It is interesting to note that there have been serious and expensive contractual disputes recently in Australia regarding the terminology of “primary” and “secondary” ventilation. In one case, the contractor ultimately went into liquidation over this matter. A typical dispute arises where the contract states that the mine owner is responsible for “primary” ventilation and the mining contractor is responsible for “secondary” ventilation.

In this paper, we propose the following definitions:

- A primary fan is one that impacts significantly on the total mine airflow. In many mines, there is only one primary fan. However, in other mines, there may be multiple exhaust or intake shafts with multiple fans on these shafts. These would all be primary fans. Primary fans are usually located on surface but this is not always the case.
- A booster fan is a primary fan that is in series with another primary fan. Without the booster fan operating, the total mine airflow will fall significantly. Booster fans are typically installed as the mine develops and the original primary fan no longer has the pressure or flow capability to service the increased resistance of the operation. In this sense, the booster fan operates as an integral and “symbiotic” unit with the original primary

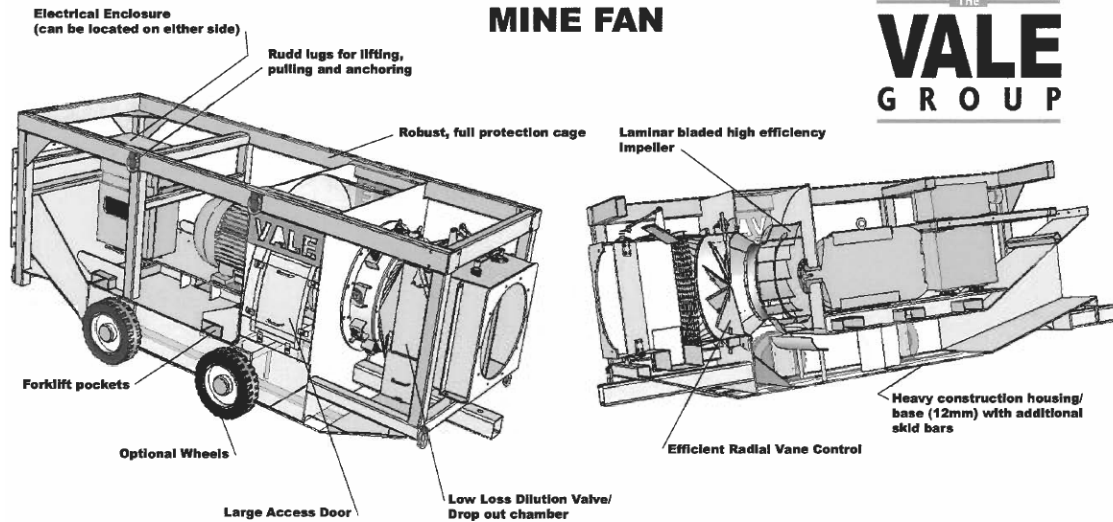
fan to provide sufficient total airflow for the mine.

- A circuit or district fan is a fan that does not significantly impact on the overall total mine airflow but does have a significant effect on a particular district or circuit within the mine.
- A development or auxiliary fan is a fan that ventilates a “blind” (dead end) heading or workplace. In most cases, the development or auxiliary fan has no impact on district airflows, although some important exceptions are discussed later in this paper.

Note that we have *not* used and consciously avoid the term “secondary” ventilation. Whilst it is a term in common use, there is little agreement about exactly what is meant by it. Some would perhaps argue that a “secondary” fan is any fan that is not a surface primary fan; however, it is difficult to put a rational, consistent and unambiguous case for this definition and we do not endorse it.

Under these definitions, it is the context that a fan is used in that determines its role, rather than the actual fan design itself. For example, a development fan (normally used with duct) can be installed without duct in a wall and effectively becomes a circuit fan. Or four development or “circuit” fans can be installed in parallel on top of an exhaust shaft and effectively become a primary fan installation.

# HIGH SPEED AUXILIARY MINE FAN



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 FAX: (02) 4869 1785  
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Figure 1. Typical coal mine auxiliary fan

Circuit, booster and auxiliary fans are a very important part of the ventilation engineer's toolbox. Not only are they essential to ventilate most dead-end headings of any length or to boost the primary fan(s), but they can also control the direction and magnitude of airflows in the mine (acting as negative regulators). In this role, they have two distinct advantages over regulators. Firstly they do not destroy pressure, so that they are more energy efficient. Second, they are relatively less affected by changes in ventilation controls at other locations, so that the district flow is usually more consistent than with a regulator. In addition, these fans can be used very deliberately to reduce the magnitude of or control the direction of leakage in various parts of the mine. In some larger hardrock mines, dozens or hundreds of circuit, booster and auxiliary fans will be in use absorbing many megawatts of electrical power, often in excess of the surface fans. Careful management of these fans is therefore not only important from a safety and operational point of view, but also in terms of managing mine capital and operating costs.

This paper concentrates on many of the practical design and operational issues that cause problems with booster, circuit and development fans.

## 2 DEVELOPMENT OR AUXILIARY FANS

Development or auxiliary fans in this context are used to ventilate blind headings using duct. Certainly there are applications in which fans are used to "throw" air into a heading without using duct (e.g. a Venturi fan) or used as an air brake, air curtain or air mover without duct to reduce or increase airflows through a particular split of air or to increase the

wind speed or "scour" a particular region of the working place; however, these "ductless" applications are not discussed in this paper. An auxiliary fan in this paper has duct on one or both ends and may have a bellmouth on the intake or an evasé on the outlet, but not both a bellmouth and an evasé. By contrast, a circuit fan will normally have both a bellmouth and an evasé (Fig. 8).

There are substantial differences between auxiliary fans used in coal mines and those used in metalliferous mines. Coal mine auxiliary fans (Fig. 1) are normally centrifugal fans employed in exhaust configuration and need to have flameproof motors, usually have the motor out of the air stream, be constructed of special materials, have provision for degassing the heading, and often have integral trickle dusters at the outlet end of the fan. They are large, heavy and expensive.

By contrast, hardrock auxiliary fans (Fig. 2) are usually axial fans and are much simpler, lighter, cheaper and smaller, even though they are frequently much higher powered due to the high flow requirements for the larger diesel engines in hardrock mines.



Figure 2. Typical metalliferous (hardrock) mine auxiliary fan

### 3 FORCING (BLOWING) AND EXHAUSTING AUXILIARY FAN CONFIGURATIONS

Ducted fans can be used in forcing (blowing) or exhausting configurations, or various combinations of these. Both options are in widespread use, although the general rule is that “continuous” mining methods (such as roadheaders or continuous miners) use exhausting ventilation because the contaminants of gas and dust are being continuously produced, whereas “drill and blast” mining methods use forcing ventilation because the gas and dust is largely produced during the blasting process.

The advantages and disadvantages of the two methods are shown in Tables 1 and 2.

Table 1. Advantages and disadvantages of exhaust system of auxiliary ventilation

Advantages	Disadvantages
- Immediately removes dust and gas produced at face	- Tube diameter can constrict activities in low seam heights
- Gets constant extraction quantity (for short ducts)	- Due to its weight and rigidity, it is more difficult to handle, transport and store
- Removes heat and humidity produced at face	- Cost of tubes
- Option for trickle duster at discharge end of fan	- Damage to tubes by passing vehicles
- Easily extended	- Potential for gas through fan
- Fan out of way in return	- Cost and weight of fan (especially if bifurcated type)
	- Low face velocity (low scouring of face)
	- Difficult to identify leaks as under suction
	- Needs electrical interlocks
	- Safety issue of personnel being sucked up the tube

Table 2. Advantages and disadvantages of forcing system of auxiliary ventilation

Advantages	Disadvantages
- Positive pressure at face	- If used with continuous mining, may force dust on operator which is then not dispersed or extracted
- Duct (flexible) is cheap	- May require dust filters
- Duct is easy to handle, transport, store	- Duct is very easily damaged
- Fans are much cheaper, simpler, lighter	- Noise from fan in intake/travel road
- Fan is in the intake	- Tramming is in return air from face
- Provides fresh air to face	
- Better for outbursts	
- No de-gassing boxes etc required	
- Can extend longer distances	
- Doesn't need to be kept as close to the face	
- Easier to detect leaks (under pressure)	
- No gas passing through fan	
- Quieter as longer ducts possible (so fan is further from face)	

Common problems with all auxiliary duct systems (blowing and exhausting) are:

- Leakage reduces face flows below fan flows
- Compared to the relatively “set and forget” nature of circuit or primary fans, auxiliary systems are very dependent on the operators to maintain standard and therefore effectiveness

- In most cases, the systems only ventilate one side of the face. It is common for a Venturi fan to be used to improve air distribution in the face region.

### 4 OPEN MOUNTED FANS

Ducted auxiliary fans can therefore be used in two ways:

- Hung from the back/roof or placed on the ground (open mounted fans), or
- Installed in or through a wall (wall mounted fans)

A basic design principal for any fan is to avoid recirculation of air from the fan outlet back into the fan inlet. This is especially true of ducted fans where the nature of a blind heading is that the air leaving the heading is often passing close by to the fan inlet. Several “rules of thumb” are used to ensure there is sufficient “bypass” air so as to avoid recirculation:

- The airflow through the district must be equal to the sum of the “open flow” (i.e. without resistance) volumes of all fans in the district plus an additional 30% of the “open flow” volume of the largest fan in the district.
- The airflow through the district must be at least 30% greater than the sum of the “open flow” volumes of all fans in the district.
- The airflow should be such that at least 0.5 m/s of air bypasses each fan.

Each of these approaches has weaknesses. For example, if an auxiliary fan has an open circuit flow of 10 m<sup>3</sup>/s, then under the first rule, the bypass airflow would need to be 3 m<sup>3</sup>/s. If the heading in which the fan is located is 3 m x 3 m, then the bypass airflow has a wind speed of 0.33 m/s—low but perhaps sufficient. However, if the heading is 6 m x 6 m, then the bypass wind speed is less than 0.1 m/s, i.e. imperceptible and unlikely to avoid recirculation.

Note that auxiliary fans and ducts are usually selected on the basis of meeting the required face airflow at the “longest” duct run that is required. However, in terms of preventing recirculation at the fan, the system should be carefully designed so that the fan will not short-circuit even when the fan is at its highest flow in the system (usually when the duct is at its shortest).

Our recommendation (apart from meeting statutory requirements) is for the bypass flow to be at least 0.5 m/s when the fan is at its highest flow in that fan/duct application and for the fan to be located at least 10 m from the return airflow.

Note that technically, the auxiliary fan must be selected so as to not only overcome the duct friction, but also the frictional pressure loss of the “return” air in the dead-end heading outside the duct. However, in virtually all practical cases, this frictional pressure loss is so small compared to the duct friction loss that it can safely be ignored.

## 5 WALL MOUNTED FANS

A wall-mounted fan is not only a fan that is mounted in a sealed wall, but also a fan that has duct passing through a sealed wall (Fig. 3). In both cases, the fan not only sees the resistance of the duct, but also some of the system resistance before the wall. This type of installation creates a “hybrid” auxiliary fan—one that overcomes the duct resistance and also part (or sometimes all) of the district or mine resistance.

Wall mounted fans have advantages and disadvantages compared to open mounted fans.

These include:

- Providing they are sealed into the wall, wall mounted fans cannot recirculate at the wall, eliminating a key safety concern with open

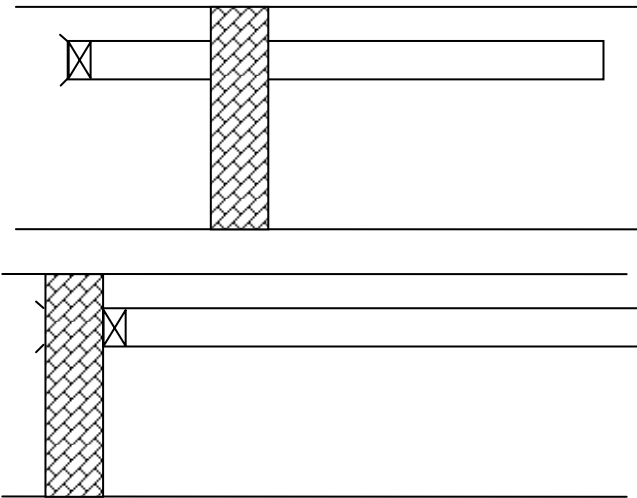


Figure 3. Wall mounted fans

mounted fans. Note however, that there is still the potential for recirculation to occur via parallel connections around the wall, although the potential for this is usually low in practice.

- Because they cannot recirculate at the wall, wall mounted fans do not need a “bypass” airflow allowance, which often reduces the total mine airflow requirement, saving capital and operating costs. This is a particular advantage if the air must be chilled as chilled air is expensive.
- Because air travels at typically about 20 m/s in a duct, but at perhaps 1 to 2 m/s in normal development, then if a wall mounted fan is a forcing fan, the air reaching the face must faster than if the fan is open mounted. The air reaching the face cannot be contaminated by diesel or other fumes or gases or moisture in this region and due to the fast transit time, cannot pick up as much sensible heat. For this region, wall-mounted installations are usually much preferable where the mine operates with refrigerated air as the temperature increase from the fresh air raise to the face is usually much lower than if the air is allowed to leave

the fresh air raise, drift along the open development to an open-mounted fan, and then be ducted to the face.

- Wall mounted fans can be used on a sealed fresh airway (if blowing fans) or a sealed return airway (if exhausting fans) to overcome the duct resistance and the resistance of the airway. An effective self-closing damper must be installed in these cases to ensure the airway itself does not recirculate. This feature of wall-mounted fans is especially important if a major airway has many such fans mounted on it. If the airway is not sealed, then a circuit or other fan is required to ensure that the airway does not recirculate. However, sizing this circuit fan can be problematic as it must be sized for the maximum number of wall mounted auxiliary fans that might be on at any time, which means that air will be wasted when fewer fans are in use. However, if the raise is sealed and the auxiliary fans properly selected, then the system is self-regulating without a circuit fan.

## 6 NUMBERS OF DUCTS AND FANS

There is now a large variety in diameters, unit lengths, materials and construction methods for both rigid and flexible duct. In general, the cheaper and poorer quality duct is employed for “one off” situations where the duct is basically sacrificial. In situations where the duct will be recovered and reused, or where the installation is critical (e.g. very long duct runs, then higher quality duct should be employed.

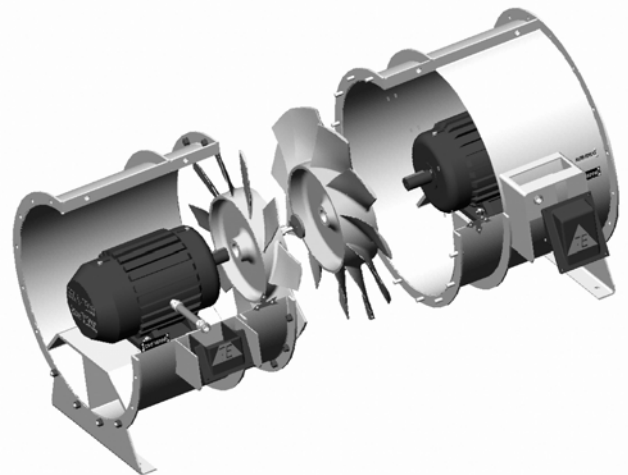


Figure 4. Two stage, two motor, contra-rotating axial development fan (courtesy SDS Ausminco)

Exhaust duct must always be rigid and is almost always recovered. Due to manual handling issues, it is usually short lengths (typically 3 m) and this also fits in with the requirement for exhausting duct to be close to the face at all times.

Forcing (blowing) ducts are usually flexible and are the preferred option for hardrock mines due to the lower cost and ease of storage and installation. They can also be further away from the face due to the “nozzle” effect of air scouring the face even when the duct is 15 to 20 m from the face. This is an advantage in hardrock mines as they employ drill and blast techniques which obviously damage any nearby duct. Ventilation should always be turned off before blasting and the duct should either be removed to 50 m from the face, or a “sacrificial” length kept close to the face, so that duct extensions are added one duct length back from the last duct length.

Where the duct runs are short, then it is usually more convenient to use short lengths of duct (20 m) but when the duct runs are long (300 m or more) then it is highly beneficial to use 100 m lengths of duct. This significantly reduces leakage through the duct as, for well-maintained duct, most of the leakage occurs at the joins so that the fewer joins, the lower the leakage.

With long duct runs, it is very desirable to have at least two parallel ducts. This provides for maintenance on the ducts and also for a minimum airflow to clear gases or heat even if one duct (or one fan) is off. For example, if one duct is damaged, then it must be turned off for repairs to be made safely and effectively. If there is no parallel duct, then either a special duct must be run for the repair job, or the work must be undertaken without ventilation.

The fact that auxiliary fans of the axial type can be used so easily in series, or in parallel, or in series-parallel provides great flexibility in selecting the correct combinations of fans and ducts for virtually any hardrock development application.

## 7 INTEGRATED SERIES FANS

Auxiliary fans purchased as a paired set of two impellers in series, each with its own motor, are now common in hardrock applications. An example is the SDS GAL 14 (twin 90 kW) fan shown in Figure 4 with fan curve shown in Figure 5. In this fan, the two stages (impellers) are contra-rotating (i.e. spin in opposite directions). This effectively removes the need for inter-stage guide vanes, reducing the cost, weight and length of the fan. A common misconception by operators is that these fans can be “split” into their two components and operated as two identical single-stage fans. However, in the case of this fan, the impellers have different numbers of blades and the performance of the fan as two separate stages is very different (and much poorer) than that of the two stages operating as a single integral unit. For example and with the fan split, at a flow of 25 m<sup>3</sup>/s, stage 1 will provide 450 Pa and stage 2 (by itself)

would provide 1400 Pa but joined together, the unit would provide a FSP of almost 3800 Pa.

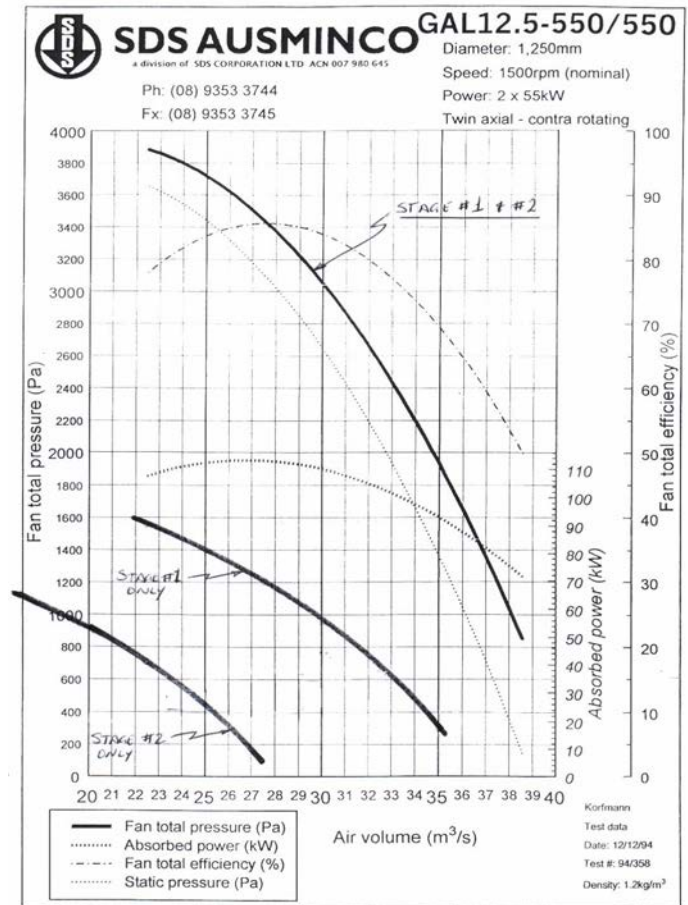
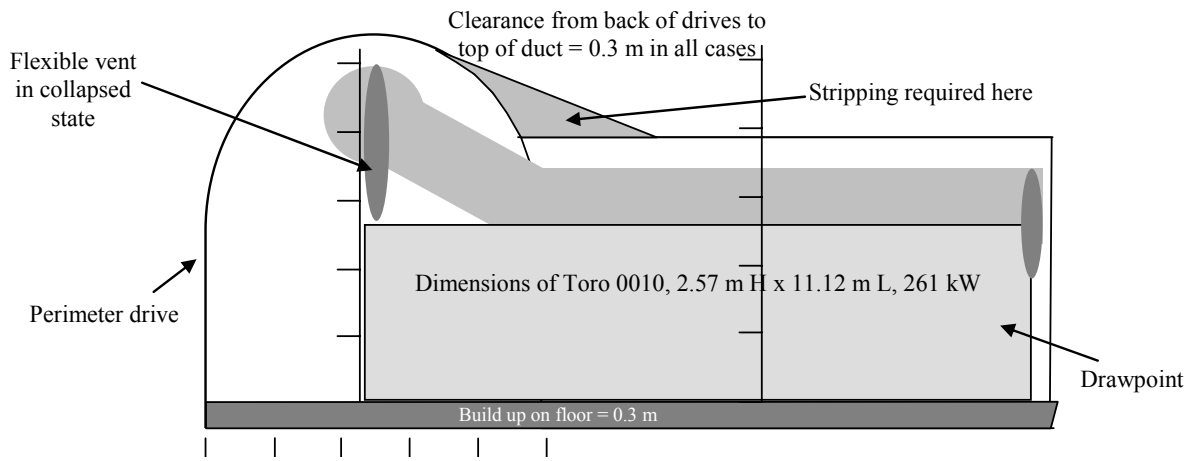


Figure 5. Fan curve for two stage, two motor, contra-rotating axial development fan (courtesy SDS Ausminco)

## 8 GENERAL ISSUES

An important point is to take into account leakage in the duct, and also to take into account any additional resistances on the system inlet or outlet that are not already included in the fan curve. For example, if an exhausting auxiliary fan is supplied by the manufacturer with an evasé, but this is removed by the operators, then the fan static pressure curve will be affected (adversely) and must be adjusted for the additional losses. A similar situation arises if a bell-mouth is removed, although in this case, both the fan static pressure and fan total pressure curves are affected.

It is very important that open mounted fans are installed where they will not be damaged by equipment, especially if the duct is to have a long life and/or is very long. If the fan is installed as an exhausting fan, then it is located in the return airway that usually has lesser traffic. However, if the fan is a blowing fan, then it will be installed in the intake air way, which is usually the principle route for people



1. Main drive is 5.7 H x 5.0 W. Assume 1.4  $\phi$  duct hung centrally in back of perimeter drive. Assume clearance from back to duct is 0.3 m. Clearance under duct to floor (assuming 0.3 muck on floor) is 3.5 m when duct inflated. If flexible duct is not inflated, it hangs down 2.2 m, not 1.4 m, reducing clearance from 3.5 to 2.7 m. Hence need for semi-rigid poly duct in this region.
2. Note that intersection of perimeter drive with every drawpoint will need to have back stripped else "T-piece" will foul on equipment in perimeter drive.
3. Drawpoint is 4.2 H x 5.0 W. Assume 1.1  $\phi$  duct. Note that clearance under inflated duct is 2.3 m (insufficient for LHD) and even less if duct is not inflated. Hence drawpoint must be wide enough to fit vent duct in shoulder so that it is safe whether duct is inflated or not.

Figure 6. The profiles and dimensions of development must be carefully considered for satisfactory auxiliary ventilation operation, taking into account intersecting development, duct clearances when inflated and uninflated, and equipment dimensions loaded and unloaded

and equipment. The development profile, mobile equipment and fan/duct combination need to be carefully selected so that they are compatible. In addition, if the duct is flexible, then it will hang down lower when uninflated and this also needs to be taken into account. Recommended clearances are shown in Table 3. These are based on ventilation duct in the middle of the back/roof. Often, the duct is placed in one corner of the roof, in which case, the table can be adjusted.

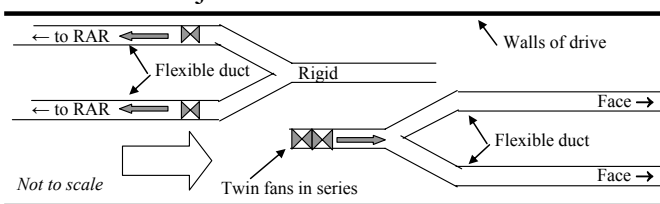


Figure 7 Push-pull system with centre overlap (plan view)

Table 3. Recommended duct clearances for critical auxiliary ventilation installations (duct in centre of roof/back)

	Hardrock	Coal
Clearance from design floor to true floor (due to muck/dirt/coal left on floor)	0.3 m	0.1 m
Clearance from top of full (heaped) truck or shuttle car tray to duct	0.3 m	0.2 m
Clearance from top of duct to design back/roof	0.3 m	0.2 m
Allowance for occasional <i>minor</i> under-break or irregularities on floor or back, or for <i>slightly</i> over-filled trucks or cars	0.3 m	0.2 m

Hence in a hardrock mine, if the *heaped* truck height is 3.5 m and the duct diameter is 1.4 m, then

the design development height should be  $3.5 + (4 * 0.3) + 1.4 = 6.1$  m. The finished height (allowing for road base) would be 5.8 m. It is also very important that if the duct must pass across an intersection, that the heights of the development do not force a poor installation where the duct is constantly being rubbed or struck by passing vehicles. An example for a hardrock application is given in Figure 6. This clearly shows the importance of stripping the back/roof where development of dissimilar heights meets and auxiliary ventilation is required to pass from one to the other.

A further issue with ducting is that duct should never be run in close proximity to firing lines (blasting cables). Incidents have occurred where flexible duct has rubbed through the protective sheathing on firing lines and accidental ignitions have subsequently resulted due to a static electrical discharge from the duct to the firing line. Coal mines are required by law to use FRAS ducting (fire resistant, anti-static).

## 9 OVERLAP SYSTEMS

As noted earlier, long blind development headings are best serviced by twin ducts to provide some redundancy and means of repairing each duct. If "leak free" rigid duct is employed, then fans can be spaced inside the duct at appropriate intervals to develop the necessary system pressure to provide for virtually any length of duct run. However, if flexible duct is to be employed, then fans cannot be located along

the duct as this is generally not practical especially since the face is constantly advancing. An overlap system can be effective in these circumstances (Fig. 7, shown at completion).

The typical operation of the overlap system is:

- A single blowing fan and duct is used to develop a certain distance
- As the amount of equipment increases in the heading due to its length, a second blowing fan and duct in parallel with the first is used to develop to the “overlap” point which is usually about the mid-point of the expected completed heading length
- The fans are then advanced to the overlap point (the ducts left in place) and new fans attached to the original duct at the overlap point. A “Y” piece and short length of larger single duct is often used at the overlap point to avoid the need for four ducts to be across the back/roof of the heading. The original ducts are then operated in “reverse”, i.e. still as blowing ducts but from the overlap back to the start of the drive. The face continues to be advanced by installing new twin ducts from the overlap to the face.

Centre overlap systems such as this result in hotter delivery temperatures (due to the air travelling more slowly in the first half of the heading, and also due to diesels operating in the intake air in this first half), require more air (to ensure no recirculation at the overlap section), require more fans, the overlap section must frequently be higher (roof stripped) and wider, electrical power must be run to the overlap section for the fans, and the system will result in at least some recirculation in the first half of the heading due to leakage from the return duct directly into the intake. However, overlap systems do ensure that the “first” part of the development is still in “fresh” air, which can be beneficial if diamond drillers or other activities need to take place while development is continuing. In addition, they can substantially reduce the re-entry time after blasting, as only the “face compartment” needs to be cleared of fumes as the return fan carries any fumes away within the vent bag itself. The re-entry time issue can become a key design requirement for these long headings, especially if they are “high priority” jobs and set up to have independent ventilation to the rest of the mine so that they can “fire anytime”.

To avoid recirculation, the length of the overlap region is very dependent on the velocity of the “bypass” air. The higher the velocity of bypass air, the shorter the overlap can be and vice-versa. A minimum velocity would be 0.5 m/s and the corresponding overlap distance would be about 10 diameters (of the development heading in which the overlap occurs).

## 10 BOOSTER OR CIRCUIT FANS

Booster and circuit fans do not have duct connected at either end of the fan. They therefore normally include both a bellmouth and an evasé, as shown in Figure 8.

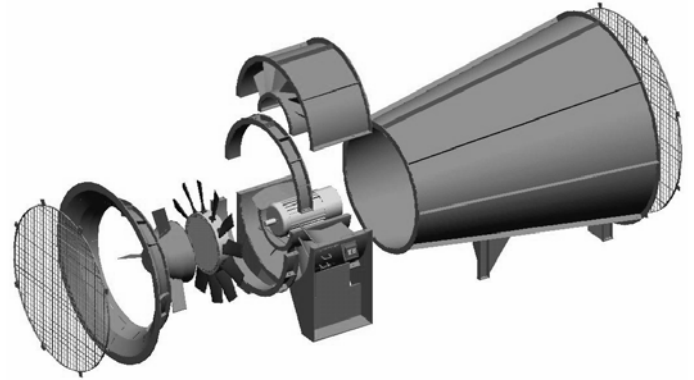


Figure 8. Circuit fan (note bellmouth and evasé on ends, and mesh guards on both ends)

Note that whilst booster fans are in series with a primary fan, they are physically separated from the primary fan. It is very important to ensure that, if the primary fan goes off, the booster fan does not go into stall, and vice-versa, i.e. if the booster fan goes off that the primary fan does not go into stall. A similar rationale applies for circuit fans.

It is also important to ensure the physical layouts of the fans allow them to be safely serviced in-situ and/or removed for repairs without compromising the other fan. In a hardrock mine, this can be achieved either by a door in the wall containing the fan, or by a bypass drive (Fig. 9). In the case of a coal mine where the exhaust usually consists of multiple roadways in parallel, the bypass arrangements are more complex, especially since the motors must be set up in intake air.

## 11 FAN PRESSURE

Technically, the pressure losses in any ventilation system such as a mine are: the inlet losses from atmosphere into the intakes, the frictional losses (including the special frictional loss call shock losses) within the mine, and the unavoidable loss of (velocity) pressure at the exhaust outlets from the mine back into the atmosphere. In theory, the correct solution for fan pressure problems is to sum these losses and then apply the fan total pressure(s) (FTP) to overcome them. However, this is a complex and usually unnecessarily complicated approach. The more prudent approach is to use only fan static pressures (FSP) to overcome the system pressure losses. As FSP is always lower than FTP, this usually builds a small measure of conservatism into the fan selections.



units, and, even as a pair, they are often quieter than the equivalent contra-rotating fan.

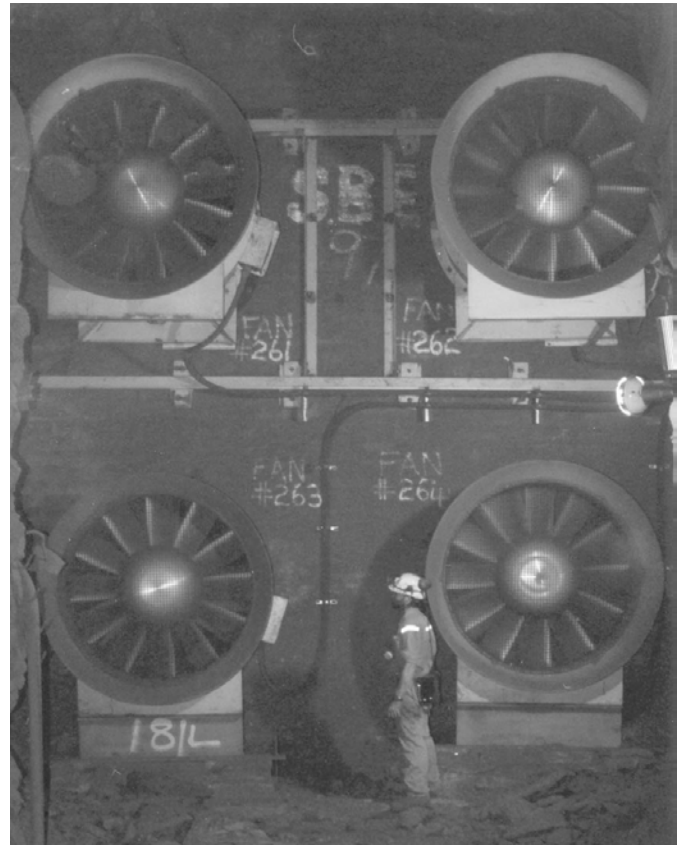


Figure 10. Four 132 kW fans installed in parallel in underground mine

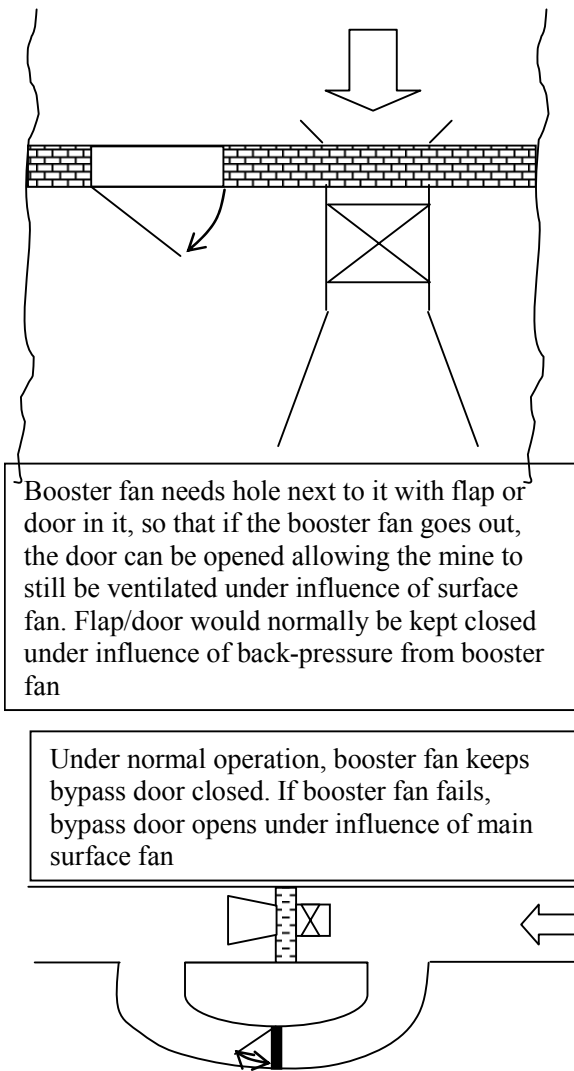
### 13 PARALLEL FAN INSTALLATIONS

There are a number of potential problems with fans installed in parallel, such as in Figure 10. It is important that both the fan inlets and fan outlets are free of obstructions and provide good flow paths into and out of the fans. Some manufacturers recommend a baffle be installed between parallel fans to avoid one fan “starving” the other fan (Fig. 11).



Figure 11. Baffle between parallel fans

A key issue for fans in parallel is to ensure they do not operate in the stall region. The situation is illustrated by the fan curve for four identical fans in parallel shown in Figure 12. In this case, all four fans can be started (one after the other) because the



Booster fan needs hole next to it with flap or door in it, so that if the booster fan goes out, the door can be opened allowing the mine to still be ventilated under influence of surface fan. Flap/door would normally be kept closed under influence of back-pressure from booster fan

Under normal operation, booster fan keeps bypass door closed. If booster fan fails, bypass door opens under influence of main surface fan

Figure 9. Two methods for providing bypass to an underground booster fan

It is important when selecting a fan to carefully consider the air density going through the fan, correct size the motor (and drives, if applicable) and to ensure the fan curve is shown as FSP and is shown at the correct impellor speed.

### 12 SERIES FAN INSTALLATIONS

In a series fan installation (the outlet of one fan is the direct inlet to the next fan), there is only one loss of fan velocity pressure (FVP) at any given flow, so that the “normal” rule of summing the individual FSP values of each fan is not correct. The true combined fan FSP at any flow is the sum of the individual FSP values *plus* the FVP of the first fan. A further exception to the normal rule for adding fans in series is when the fans are specifically designed to operate as a series unit. An example is the two-stage contra-rotating fans discussed earlier.

Note that in some circumstances, it is preferable to purchase two identical axial fans (e.g. two 90 kW fans) and bolt these in series, rather than purchasing a two-stage contra-rotating axial fan (180 kW two-stage, two-motor fan). Advantages of the separate fans is that they can be “split” into two identical



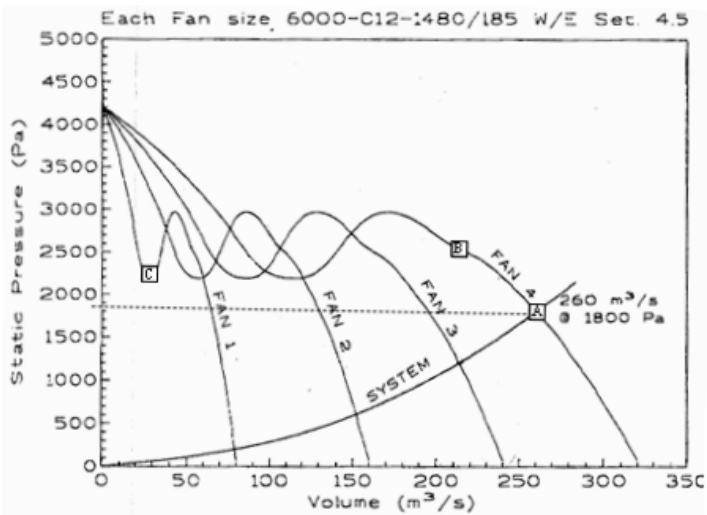


Figure 12. Single and combined fan curves for four identical fans operating in parallel

final system operating point (A) is below the lowest stall point of any of the individual fans. Note that if the ventilation officer did not know the “stall region” for each of the fans (as is often the case), then he/she might conclude that this system could safely operate at point B, but this is *not* the case. This fan system *cannot* operate reliably at point B even though point B is well below the stall point of any of the individual fans. Note that this issue is particularly important at higher fan pressures as the “deep stall” at point C for any of these fans will become “deeper” (lower) as the blade angle is made more aggressive and the fan motor power increased. This means that a parallel installation of such fans becomes increasingly *low pressure* as the blade angle is increased. It is therefore very important for the fan manufacturer to be consulted before proceeding further on a parallel fan system.

#### 14 FAN DUTY

Some discussions have already been provided concerning the important issue of nominating a fan duty. It is very important that all details be provided to the fan manufacturer before a fan is selected.

Of particular importance is for ventilation models to have correct airway dimensions, lengths, friction (“k”) factors and make adequate provision for shock losses and leakage. Fan curves should be based on FSP values.

Where a fan is a booster or circuit fans, it will be part of a “system” that includes other fans. It is very important to note in these cases that the system resistance curve as seen by this fan will not pass through the “origin” (0 m<sup>3</sup>/s and 0 Pa). It is very important, therefore, for the ventilation officer to give not only the required fan duty to the fan suppliers in this case, but also the expected system operating curve. Consider the situation shown in Figure 13 in which a circuit fan is required to meet a duty of 100 m<sup>3</sup>/s at 2500 Pa FSP. Assuming a normal system resistance

curve (curve A), the single fan appears to be well suited to the duty as the depth of the stall point is not relevant for a single fan starting up under normal conditions (along curve A). However, in this case the fan operates in parallel with others creating a system resistance for this fan of curve B. The depth of the stall point (often not known to the ventilation engineer) combined with the fact that the system resistance seen by this fan does not pass through the “origin”, will create serious problems as the fan will have to pass through the stall point as it spins up and may in fact become locked in stall. If only the fan duty is provided to the fan supplier, and the fan is only evaluated on the basis of this duty, then once the fan is installed, it simply may not operate at the duty at all.

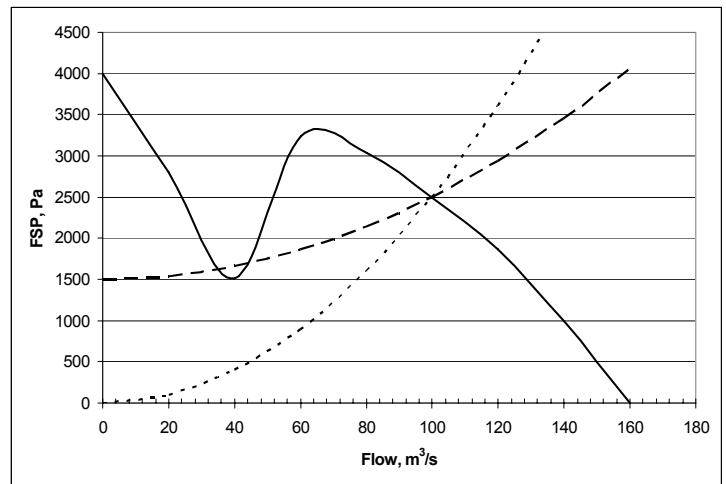


Figure 13. System resistance curve for underground circuit fan

#### 15 FAN PIECES

It is important that underground fans be provided with sufficient spare parts, including spare fan pieces. The performance of the installation will fall, sometimes very significantly, if the fan is meant to include an evasé but it has been removed, or is meant to have a bellmouth but it has been removed.

From a safety point of view, fan inlets and outlets (except where duct is attached) should have a safety screen.

If there is any potential for air to want to flow “backwards” through a fan when it is off, then it must be fitted with a self-closing damper (SCD). These come in various designs. The cheapest is the simple “butterfly” type installed between the fan outlet and the evasé. This provides for the physically smallest SCD and therefore lowest cost. However, as the velocity pressure is high in this region, the SCD is relatively inefficient. A more efficient design is for the SCD to be installed at the outlet of the evasé, where the velocity pressure is already low, so that any shock losses associated with the SCD (when open) are also low.

When fans are horizontal, then SCD butterfly leaves mounted vertically work satisfactorily. How-

ever, it is important that they are mounted correctly. If they are not mounted correctly, then they may not close when required, or may not open when required, both of which will result in problems. It is also important that if the SCD is designed to be in a particular location on the fan then the manufacturer should be consulted before mounting it somewhere else on the fan. We are familiar with a situation in which a circuit fan had a self-closing damper on the inlet and a easé with an inner fairing on the outlet. The operators decided to move the fan to a different location. At the new location, the SCD was changed to the outlet side of the fan and the inner fairing on the easé was removed to allow the SCD to continue to open and close. The fan went into stall and the subsequent investigation revealed that its peak pressure performance had fallen from 2400 Pa to 1600 Pa!

When fans are mounted vertically, then the SCD usually requires a counterweight so that it will work effectively without destroying excessive pressure when open.

## 16 FAN INSTALLATIONS AND MOUNTING

Where fans are mounted into a sealed raise that requires pedestrian access (e.g. to a ladderway, or to take refuge from a fire), it is very important that airlock pedestrian doors are fitted if the pressures are excessive, which they often are. In a recent case, a mine surveyor lost part of his finger when a pedestrian door with excessive pressure closed on it.

## 17 FAN IDENTIFICATION

In mines with many underground fans, it is important that an identification system be adopted. Key elements include:

- Casings colour coded by fan type
- Manufacturer's name
- Motor kW
- Fan diameter
- Arrow for airflow direction
- Arrow for impeller rotation direction
- Steel boxing for forklift tynes transport and also for mounting either from back/roof or on floor
- Note that airflow and impeller directions should be welded onto casing as well as painted

The fan diameter and motor kW should be painted at four locations at equal angles around the external circumference of the fan casing, so that these can be easily read from all directions.

## 18 ON/OFF INDICATION AND RE-STARTING FANS

In large hardrock mines with dozens and sometimes hundreds of underground fans, it is common to find one or more fans off when they should be on. Important fans should have on/off and amps indication back at a remote monitoring point, or at the very least, should have double indicator lights at an easily visible location. For example, critical fans in a return airway that is not easily accessible should have twin lights (per motor) at an external location that is easily travelled.

In many cases, fans can now be automatically turned on and off using ControlPED™ or other technologies.

Re-entry times after blasting are very dependent on when auxiliary ventilation can be re-established, bearing in mind that the re-entry time is actually the time after ventilation is re-established and not after the blast occurs as such. If fans need to be started manually, then this can delay re-entry. In addition, manual re-start means that fan starters must always be in fresh air to allow safe access for re-starting, which can be difficult or expensive to achieve in some circumstances. Alternative options include automatic re-start based on a time delay (i.e. a timer is built into the fan starter so that, if the timer is pressed and the fan is turned off, then it will automatically re-start (say) 10 minutes later). ControlPED™ and other technologies can also be used to re-start fans.

Most fan starters used with flexible duct today will provide an automatic pulse start so that the duct is not blown apart on start-up.

Monitoring fan amps is an important proxy for fan condition. If amps are much lower than design, then it is possible that the blades have worn and the fan is no longer performing.

## 19 SUMMARY AND CONCLUSIONS

Booster, circuit and auxiliary fans play a critical role in underground mine ventilation. There are many important factors that need to be adequately understood for safe and effective use of these types of fans. New opportunities are being developed for using these types of fans and in some cases, new modes of operation of these fans are making new mining methods possible or providing significant potential increases in productivity or reduction in capital or operating costs of existing mining methods.