Metal Mining

Mine ventilation fan specification and evaluation*

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ABSTRACT

This paper deals with specifying and evaluating fans for mine ventilation projects. Topics such as fan and equipment design life, operating points, and operating conditions are discussed. Common operating problems, such as vibration, parallel operation, mechanical failure, erosion, corrosion, and deficient fan performance are covered. Apart from identifying the potential operating problems, likely causes and suggested remedies are given. Fan type, fan accessories, and likely system effects and fan testing are discussed. Suggestions on what should be covered when evaluating different fan options and proposals and suggestions on the verification of supplier claims and guarantees, including cost of operation, the evaluation of initial capital cost, estimate on maintenance costs, and likely replacement expenditure over the life of the fans. In addition, fan reliability, operational flexibility, suggested construction details and fan vendor past history and experience are reviewed.

Introduction

Currently, many major mining corporations continue to reduce the size and capabilities of their own engineering departments increasing their dependency on vendors, therefore they must develop guidelines that will ensure their needs are clearly defined. In today's environment, mining corporations tend to focus on their core competence—mining. On large capital development projects, services such as engineering, procurement, project management, construction, and commissioning, are often purchased from vendors. This is happening increasingly on projects such as major mine ventilation systems. In this paper, an attempt is made to give a broad picture of issues that need to be covered to ensure that the corporations' needs are adequately addressed.

Both mine operators and fan manufacturers need to understand the critical nature of a reliable fan system to the mining operation. Everything possible must be done in the design and manufacture of main ventilation fans to ensure operational reliability. Based on the authors' experience, important design parameters and criteria are outlined and discussed.

Design Requirements

Definition of Fan Operating Requirements

Over the anticipated life of a mine's ventilation system, the operating requirements will invariably change. A network analysis is needed in order to establish the likely fan operating conditions. Because of changes in mine layout over time, the mine ventilation characteristic curve is not constant. Mine airflow and energy/pressure losses in the ventilation system requirements can be reasonably predicted for various stages throughout the life of the mine. This change in mine resistance requires that fans be selected for continuous operation over a range of operating duties.

Design Life

In most instances, the likely life of a mining operation is well-established during the project evaluation. A reasonable minimum design life for major ventilation equipment is 25 years of continuous operation. The major components that need to be covered by this requirement are fans, flow control mechanisms, ducting and dampers, motors, starters, and, if applicable, variable speed drives. Especially with products that are new to the market, it is important to ensure the availability of product support and spare parts for the duration of the design life. Equipment with microprocessor control, such as large variable frequency drives, needs to be carefully studied. The manufacturer needs to have an equipment design policy that allows for future upgrading when the microprocessors become obsolete.

Operating Points

Operating points that clearly define the range of the ventilation requirements need to be established. By establishing the minimum and maximum duties, an operating envelope is defined. As a refinement, other anticipated operating points need to be defined within the operating envelope. A likely timeline of when and for how long the ventilation system will operate at each of the points needs be considered. Apart from meeting planned operating points, consideration should be given to fan performance flexibility to adapt to unplanned changes in operating conditions.

Two or more main fans operating in parallel have a number of advantages over a single fan. An advantage of this arrangement is that, in the event of a fan failure, the remaining operational fan(s) can still achieve up to 70% of the normal airflow rate. The use of fans in parallel requires special attention to layout and configuration details. Parallel operation may entail additional isolation dampers and air lock doors.

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Operating Conditions

The operating conditions affect the type of equipment, the equipment layout, materials used, and the equipment design. Operating conditions include the air temperature range, dust loading, moisture, pH level, etc. Low ambient temperature can cause problems with steel brittleness. When fans are shut down, with low ambient temperatures, ice can form in and on components of fans thereby affecting equipment availability. A condition often overlooked is the likely maintenance capability of the mine. This, alone, can determine what type of fan or control system is appropriate for a particular ventilation project.

Operational Concerns

Vibration

One of the most common causes of fan down time is vibration. Vibration problems fall into two broad categories, namely, aerodynamic vibration and mechanical/structural vibration. Aerodynamic vibration problems may be caused by the likes of a fan surge, stall (axial flow fans), rotating stall (centrifugal fans), and inlet vortex, whereas out-of-balance, misalignment, inadequate stiffness, or resonant frequency problems may cause mechanical/ structural vibration problems.

Many different factors can cause or aggravate vibration problems. Attention needs to be paid to the foundation design. This must be of adequate stiffness. If, for some reason, this is not possible, special attention must be paid to the overall foundation design and foundation mass. This is of particular importance when variable speed fans are being considered (Mukka, 1997). Variable speed operation exposes the many fan components to an infinite number of forcing frequencies. The fan resonant frequency does not fall within the limits of the fan operating speed(s). This is of particular importance if speed control is to be used in meeting different operating conditions. Coupling selection can also affect fan vibration problems especially on fan designs utilizing relatively long floating shafts. In such cases, disc pack couplings with provision for axial growth should be used. These couplings have very good angular misalignment properties, however, most importantly, the floating coupling is well-supported with very little radial displacement allowed. Depending on the air stream, build-up on the blades can also affect fan vibration. Centrifugal fans with hollow airfoil blades are susceptible to internal entrapment of moisture leading to unbalance. Blade weep holes are required to ensure that moisture does not get trapped inside the blade cavities.

Any fan assembly will have many different resonant frequencies. It is a challenge for the designer to arrive at a design in which forcing frequencies do not coincide with any of these resonant frequencies. Resonant frequencies coinciding with forcing frequencies can produce unacceptable vibration levels. Computerized modal analysis is a very useful tool to identify the most critical of these resonant frequencies. This enables the fan designers to work around potential problems thereby avoiding costly field rework. Critical shaft speeds should be well above the maximum operating speed of the fan. There must be sufficient separation between resonant and forcing frequencies to avoid excitation that may result in high vibration levels.

When purchasing fans, the purchaser needs the fan manufacturer to specify the minimum foundation mass, in addition to the minimum foundation stiffness in the horizontal, vertical, and axial directions. It is prudent to also specify a maximum allowable sensitivity to misalignment.

Parallel Operation

On a ventilation system, with fans operating in parallel, the fan vendor needs to show the area of instability (stall) on the fan performance curve (Fig. 1) by means of a "double loop." When the performance curve of a fan has a pronounced dip to the left of its peak, and when there will be two or more similar fans operating in parallel, care must be taken to ensure stable operation. This is not usually a problem with backward curved or airfoil-bladed centrifugal fans. If fans are not conservatively specified, this could be an issue on applications with adjustable blades at rest axial flow fans. The purchaser needs the fan vendor to provide assurances that for all operating points, the fans will operate successfully. Variable speed operation does not address the problem of potential fan instability.

Mechanical Failure

Because of the critical nature of large ventilation systems associated with mine production and safety, design specifications need to ensure that the potential for major mechanical failures is minimized. The adoption of conservative engineering standards will go a long way to achieving this goal.

These conservative engineering standards should cover topics such as acceptable stress levels, minimum plate gauges, minimum acceptable fastener sizes, motor service factors, coupling service factors, and minimum bearing life.

Where at all possible, tried and proven designs, technology, and manufacturing procedures should be used.

Corrosion and Erosion

The existence of either erosion or corrosion may shorten the fan life and may result in unsafe equipment operation. There are many variables, such as particle properties, material properties, particle velocity, impact angle, etc., which affect erosion rates.

Fan Performance

Even if fan performance is verified by means of a factory performance test or a model test, on-

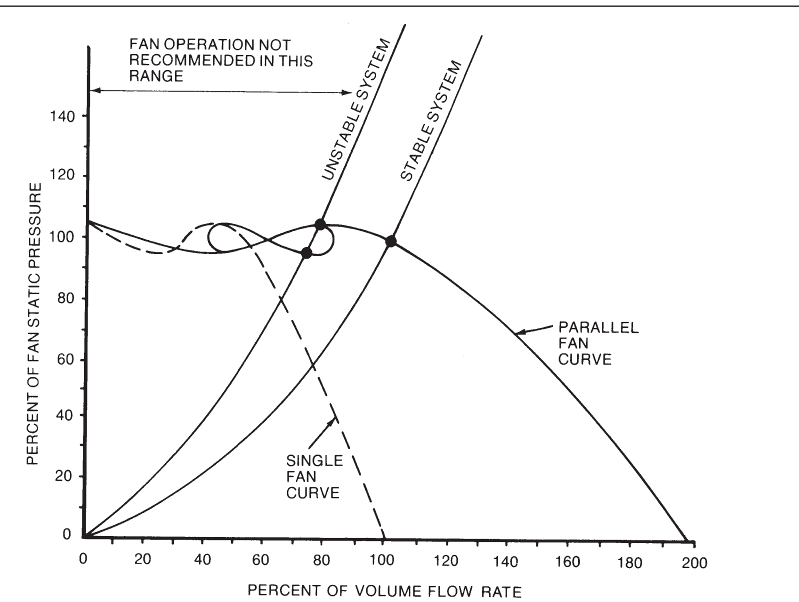

Fig. 1. Parallel fan operation (AMCA publication 201).

site performance can be significantly different from the performance quoted by the fan vendor. Fan field installations with good inlet and outlet conditions plus test measurement locations are usually a rarity. The practical geometry and circumstances of the fan installation often require consideration and compromise when conducting and evaluating field performance tests. Air Movement and Control Association's (AMCA) Publications 203 and 803 provide an insight into field testing. During the design phase, care must be taken to ensure that the flow conditions into and out of the fan are as good as possible. AMCA publication 201 provides guidelines for estimating the effect poor inlet and outlet conditions have on fan performance.

Other causes of poor performance are poor inlet cone set-up (centrifugal) and poor tip clearances (axial flow fans). Depending on the blade design, build-up on the fan blades or erosion of the fan blades can be detrimental to fan performance. Typically, exhaust fans handle return air that contains water droplets, diesel soot, etc. These fans can suffer from corrosion, erosion, and build-up. Not only is this a concern from a structural and safety perspective, but in addition, these conditions can have a detrimental effect on fan performance and fan vibration levels.

Lammel (1976) reported that on axial flow fans, the effects of corrosion, erosion, and build-up could drop the fan efficiency by up to 15%. Not only does the efficiency drop but the fan's pressure/volume characteristic is also affected.

Fan Configuration

Fan Type

Invariably, the type of fan selected is a function of a mine's past experience. Although such a decision process has its merits, the process can result in the wrong type of fan being selected. A useful cross-check when selecting the type of fan is to calculate and check the specific speed of the application. For a given volume flow and pressure, specific speed becomes a function of running speed. For the different running speed options, the specific speed calculation will show the most appropriate fan for the design duty being considered.

From Figure 2, it is evident that centrifugal fans have lower specific speeds than axial flow fans. This means that as a general rule, for a given operating point, a centrifugal fan should run slower than an axial flow fan. Stated another way, at given pressure, centrifugal fans are suited to relatively lower volumes than axial flow fans.

For example, in Table 1 (Vendor A), if:

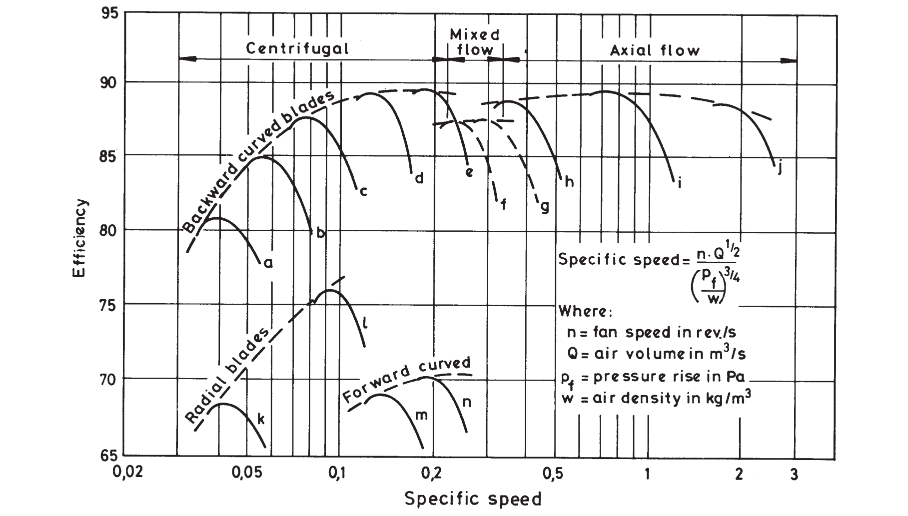

Fig. 2. Fan efficiency vs specific speed (environmental engineering in South African mines, 1989).

n =11.83 r/s
Q = 286.5 m^3/s
p_f = 7480 Pa (static pressure rise = 7.48 kPa)
w = 1.11 kg/m^3
then, specific speed = 0.27

A way to increase the specific speed of a centrifugal fan is to use double width fans. A way to reduce the specific speed of an axial flow fan is to use multiple stages.

Layout Configuration

Physical site constraints help determine the most appropriate layout configurations. Factors such as system effects, accessory losses, moisture, maintainability, and access deserve serious consideration. In most instances, a series of compromises have to be made. The compromises come down to cost vs optimum layout.

Care must be taken not to have bends and/or abrupt transitions immediately upstream or downstream of the fan. Besides affecting the system pressure losses, poorly designed and located bends and transitions can have a detrimental effect on the fan performance. This is discussed in more detail below.

System Effects

System effect is the reduction in fan performance resulting from various system components located close to the fan. The system effect losses occur because of the differences between the inlet and outlet conditions of the fan as tested and the fan as installed. The fan performance is based on uniform inlet flow and fully developed outlet flow. System components that disturb the inlet flow or prevent fully developed outlet flow will cause a reduction in fan performance.

For the design engineer to forecast with confidence the installed fan performance, he

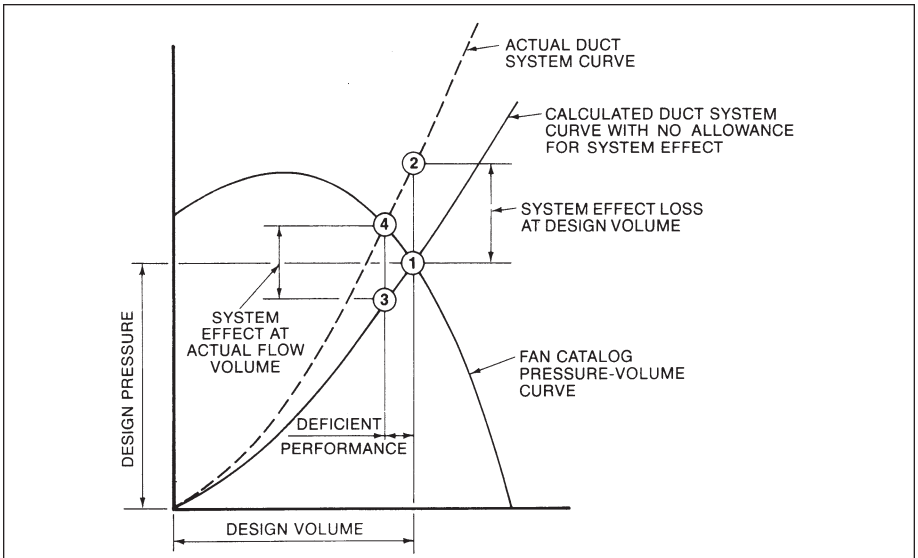

Fig. 3. Deficient fan/system performance, system effect ignored (AMCA publication 201).

Table 1. Comparative analysis of aerodynamic performance (data provided by vendors A and B)

		Fan Vendor A		Fan Vendor B	
Operating Point		**1**	**2**	**1**	**2**
Information given to the fan vendors					
Inlet volume at shaft collar – standard conditions	(m^3/s)	240	265	240	265
Mine resistance (total pressure) – standard conditions	(kPa)	4.03	7.08	4.03	7.08
Information provided by fan vendors					
Air density at fan intake	(kg/m^3)	1.15	1.11	1.15	1.12
Inlet volume at fan intake at air density at fan intake	(m^3/s)	250.4	286.5	250.4	283.4
Mine resistance (total pressure) at air density at fan intake	(kPa)	3.85	6.55	3.87	6.60
Losses up to Plane 1 of the fan (per AMCA definition)					
Concrete transition and drop-out	(kPa)	0.28	0.35	0.05	0.07
Isolation damper	(kPa)	0.13	0.16	0.02	0.02
Inlet ducting	(kPa)	0.01	0.02	0.03	0.03
Transition	(kPa)	0.13	0.16	0.02	0.03
Flexible connections	(kPa)	0.00	0.00	0.00	0.00
System effect	(kPa)	0.00	0.00	0.02	0.03
Sum of losses between exhaust shaft collar and Plane 1	(kPa)	0.55	0.69	0.14	0.18
Losses between Plane 1 and Plane 2 of the fan (for comparison purposes only)					
Inlet louver control/inlet vane control	(kPa)	0.08	0.10	0.02	0.03
Inlet boxes	(kPa)	0.09	0.11	0.12	0.15
Diffuser	(kPa)	0.02	0.03	0.04	0.05
Sum of losses between Plane 1 and Plane 2 (considered part of fan)	(kPa)	0.19	0.24	0.18	0.23
Losses from Plane 2 of the fan to atmosphere					
Discharge silencer	(kPa)	0.00	0.00	0.00	0.00
Sudden expansion loss	(kPa)	0.11	0.14	0.12	0.16
System effect	(kPa)	0.00	0.00	0.00	0.00
Sum of losses from Plane 2 to atmosphere	(kPa)	0.11	0.14	0.12	0.16
Inlet velocity pressure at Plane 1 of the fan	(kPa)	0.19	0.24	0.20	0.25
Inlet static pressure at Plane 1 of the fan	(kPa)	-4.59	-7.48	-4.21	-7.03
Inlet total pressure at Plane 1 of the fan	(kPa)	-4.40	-7.24	-4.01	-6.78
Discharge velocity pressure at Plane 2 of the fan	(kPa)	0.11	0.14	0.12	0.17
Discharge static pressure at Plane 2 of the fan	(kPa)	0.00	0.00	0.00	0.00
Discharge total pressure at Plane 2 of the fan	(kPa)	0.11	0.14	0.12	0.17
Fan static pressure as per AMCA definition	**(kPa)**	**4.40**	**7.24**	**4.01**	**6.78**
Fan total pressure as per AMCA definition	**(kPa)**	**4.51**	**7.38**	**4.13**	**6.94**
Static pressure rise	(kPa)	4.59	7.48	4.21	7.03
Compressibility factor		0.9849	0.9746	0.9855	0.9754
Fan shaft power (including bearing losses)	(kW)	1291	2339	1205	2213
Fan static efficiency	(%)	84.1	86.4	82.1	84.7
Fan total efficiency	(%)	86.2	88.1	84.6	86.7
Performance based on fan inlet area (Plane 1)	(m^2)	13.75	13.75	13.21	13.21
Performance based on a diffuser discharge area (Plane 2)	(m^2)	18.16	18.16	15.61	15.61
Fan stall at operating speed	(kPa)	6.05	9.13	5.17	7.79
Safe fan static pressure at operating speed	(kPa)	5.75	8.67	5.04	7.63
Fan static pressure/safe fan static pressure	(%)	76.5	83.5	79.5	88.9
Volume at safe fan static pressure and operating speed	(m^3/s)	169.9	217.1	165.2	206.2
Maximum power requirement at operating speed	(kW)	1291	2386	1242	2349
Operating speed	(r/s)	9.53	11.83	9.53	11.90
Tip speed	(m/s)	96.2	118.4	92.1	114.9

must know how the fan was tested and rated. In addition, he must know what effect the system and its connections will have on fan performance. The fan vendor needs to address these issues. Figure 3 clearly illustrates the effect ignoring system effects has on fan performance.

The three most common causes of deficient performance of the fan/system combinations are non-uniform inlet flow, swirl at the fan inlet, and improper outlet connections. These conditions alter the fans' performance thus their full flow potential is not achieved.

Accessories

Typical fan performance and control accessories that are purchased with fans are inlet vane controls, inlet damper controls, inlet box(es), back draft dampers, isolation dampers, inlet silencers, outlet silencers, inlet ducting, outlet ducting, inlet safety screens, outlet safety screens, and diffuser. All these accessories are located in the air stream and have associated pressure losses. Fan vendors include the losses of some of these accessories in their fan performance (inlet vane control, inlet damper controls, inlet boxes, and diffusers). It is important that the supplier clearly understands what losses are included in the mine resistance assessment and what losses need to be taken into account by the fan vendor.

The fan manufacturers or the suppliers of the accessories need to be responsible for calculating the pressure losses of those items in their scope of equipment. These accessory losses should be included and listed by the manufacturers as illustrated in Table 1 and defined as losses up to Plane 1 and from Plane 2 of the fan (per AMCA). Refer to Figures 4 and 5.

Fan Rating Practices

Fans should be rated in terms of fan static pressure and fan total pressure conforming to the definition presented in AMCA Standard 210 or AMCA Publication 801. In these publications, the fan inlet is defined as Plane 1 and the fan outlet as Plane 2 (Figs. 4 and 5). All components, including accessories located between Plane 1 and Plane 2, are considered part of the fan.

By AMCA specification:

$FTP = TP_2 - (-TP_1) = TP_2 + TP_1$

$FSP = FTP - VP_2$

where,

FTP = fan total pressure

FSP = fan static pressure

TP_1 = total pressure at Plane 1

TP_2 = total pressure at Plane 2

VP_2 = velocity pressure at Plane 2

The fan inlet (Plane 1) is defined as the plane perpendicular to the airstream where it first meets the inlet cone or the inlet box furnished by the fan vendor.

The fan outlet (Plane 2) is defined as the plane perpendicular to the airstream at the diffuser discharge.

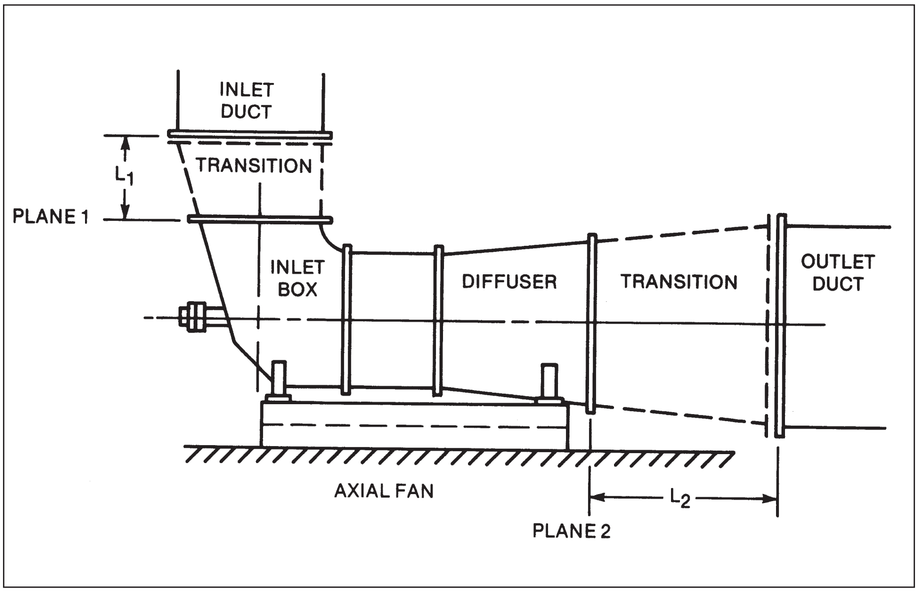

Fig. 4. Definition of planes, axial flow fan (AMCA publication 802-92).

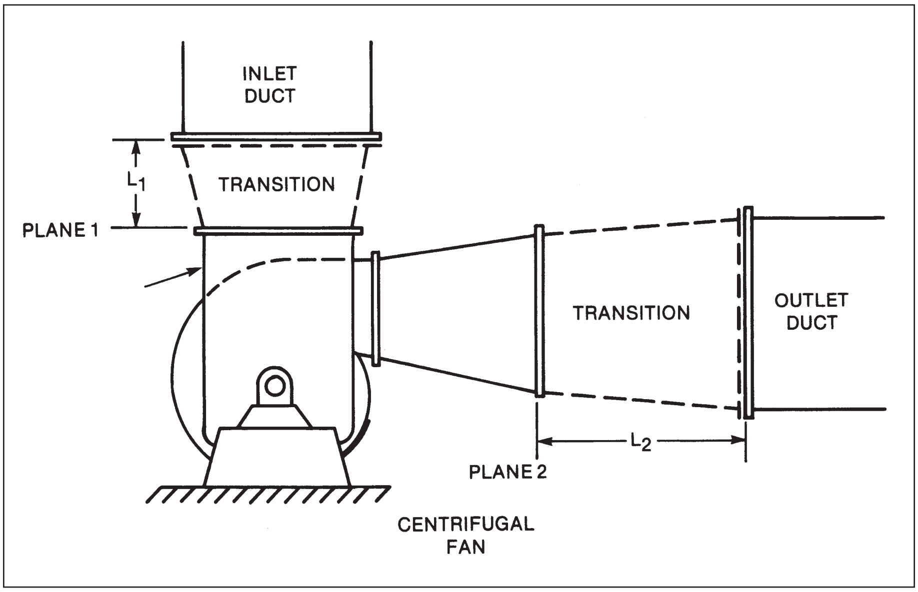

Fig. 5. Definition of planes, centrifugal fan (AMCA publication 802-92).s

Quality Assurance and Quality Control

When purchasing fans, an objective is to purchase equipment of appropriate quality for its intended use. Appropriate quality assurance standards need to be selected to ensure that this objective is met. The fan vendor needs to have a quality assurance program which is in accordance with ISO 9002 or approved equal. He needs to provide certification of this.

The majority of Inco Limited's experience on mine ventilation fans is with axial flow fans (Stachulak, 1996). On these fans, the blades are cast in batches. A full radiograph of the highest stressed lower third of each blade is required. The acceptance criteria used are that of the fan vendor.

Tight blade tip to housing clearance is required to meet the quoted performance. As part of its quality control requirement, the fan impellers are assembled into the fan housing. The blade tip to housing clearance is factory checked and verified. The acceptance criteria used are that of the fan vendor.

Fan Testing

The purchaser should consider requiring fans undergo a factory mechanical witness-run test prior to delivery and installation. The factory mechanical-run tests are designed to demonstrate that the specified vibration levels and unbalance sensitivity criteria are met. Where factory test facilities allow, full size factory aerodynamic performance tests should be performed. The tests are performed in accordance with AMCA 210-85. Where factory test facilities are inadequate for a full-size test, a model test to AMCA 210-85 is performed. It is obvious that the process of generating model performance, scaling this performance to full-size units, applying these fans to known plenum geometry and configurations, building and installing the fans, and the uncertainties of field testing, specifically fan/system performance, will result in some degree of variance from the predicted performance. The question is frequently asked, "What is the range of anticipated variance that one would expect for a particular installation?" This would best be answered by conducting a fan test at the installation site as per AMCA Standard 803-87.

A final acceptance test at the installation site ought to demonstrate that the vibration level and sensitivity to unbalance of the entire installation (which is affected by residual unbalance in the rotating assembly, foundation rigidity, and alignment of the fan and drive) are within specified parameters, and that the foundation stiffness is satisfactory.

Auditing and Commissioning

The purchaser needs the fan vendor to provide manufacturing and inspection schedules followed by regular updates which allow scheduled factory visits for auditing personnel.

Following fan installation and in addition to their standard commissioning checks, the fan vendors should verify that the margin on resonant frequencies, the vibration levels, the sensitivity to unbalance and balancing meet the contractual requirements. In addition, they are required to provide commissioning reports indicating compliance with the specifications and summarizing the condition of the fans.

Project Evaluation

Aerodynamic Evaluation

Before a comparative evaluation of different proposals is possible, it is important to ensure that all performance requirements are clearly understood by all parties. One needs to clearly define whether the inlet and outlet pressures are in terms of total or static pressure.

A review of Table 1 indicates that for the losses between the shaft collar and Plane 1, fan vendor B added 0.14 kPa and 0.18 kPa of additional pressure losses to mine resistance, whereas fan vendor A added 0.55 kPa and 0.69 kPa. In the case of vendor A, these additional losses represent an increase of 14% and 10% in mine resistance for points 1 and 2, respectively. In the case of vendor B, these additional losses represent an increase of 4% and 3% in mine resistance for points 1 and 2, respectively.

For both fan vendors, the sum of the internal fan losses (between planes 1 and 2) and the sum of the losses from Plane 2 to atmosphere are similar largely as a result of the difference in the estimation of losses from the shaft collar to Plane 1, vendor B's fan static pressure is 91% and 94% of vendor A's fan static pressure for points 1 and 2, respectively. For points 1 and 2, the difference in fan shaft power between vendors A and B is 86 kW and 126 kW, respectively. Fan vendor A appears to have a more favourable stall margin, 6.05 kPa to 9.13 kPa, than vendor B, 5.17 kPa to 7.79 kPa. Fan vendor B appears to be at a higher operating point on the fan performance curve. It is interesting that both fan vendors chose to ignore both the inlet and outlet system effects.

Besides resulting in an unbiased evaluation, Table 1 acts as a cross-check for the fan vendor to ensure that they include all the required accessory losses. It also allows the party doing the evaluation to compare accessory losses. Large differences between vendors will give the evaluator the opportunity to raise questions and ask for justifications. It may prompt further technical investigation like the necessity for conducting a laboratory model test of the fan and system coupled with a computer fluid dynamic analysis.

The fan data contained in Table 1 is helpful in the process of fan proposal analysis. It establishes a "common denominator" for all parties involved. It avoids the chance of misinterpreting fan terms and definitions. It provides a means of efficient comparative analysis.

The analysis of Table 1 reveals that two fan vendors come up with rather different fan requirements. The data provided appears to contain minor discrepancies.

Cost of Operation

In many instances, the cost of energy consumption over the life of a fan is significantly more than the initial capital cost of the equipment. Many factors affect the cost of energy. In some instances, the mine not only pays an energy cost (cost per kWh) but also pays a demand cost (cost per installed kW). In these instances, costs of operations tend to be significant and can be a major determining factor in the selection of a fan.

When undertaking a cost of operations calculation, it is important to evaluate the total power drawn by the fan(s) and ancillary equipment off the power supply and not just the fan shaft power. This ensures that all inefficiencies associated with the motors, switchgear, and drives are automatically built into the evaluation process.

Table 2 is an illustration of comparative power consumption and efficiencies quoted by two fan vendors for the same mine operating points. The difference in electrical input power for points 1 and 2 for vendors A and B is 118 kW and 155 kW, respectively. This lower electrical input power for B can be attributed to the significantly lower estimated losses between the shaft collar and Plane 1 of the fan.

Table 2. Comparative analysis of power and efficiency (data provided by fan vendors)

		Fan Vendor A		Fan Vendor B	
Operating point, one fan		**1**	**2**	**1**	**2**
Inlet volume at fan intake	(m^3/s)	250.4	286.5	250.4	283.4
Mine resistance	(kPa)	3.85	6.55	3.87	6.60
Air density at fan intake	(kg/m^3)	1.15	1.11	1.15	1.12
Motor rating	(kW)	1600	2500	1666	2600
Fan shaft power (including bearing losses)	(kW)	1291	2339	1205	2213
Motor load	(%)	80.7	93.6	72.3	85.1
Motor efficiency	(%)	94.9	95.8	94.5	95.6
Motor input power	(kW)	1360	2442	1275	2315
Variable frequency drive efficiency	(%)	95.5	97.2	97.6	98.2
Electrical input power to variable frequency drive	(kW)	1424	2512	1306	2357
Fan static efficiency	(%)	84.1	86.4	82.1	84.7
Fan total efficiency	(%)	86.2	88.1	84.6	86.7
Overall efficiency (i.e. fan static, motor, and VFD)	(%)	76.2	80.5	75.7	79.5

Conclusions Drawn from Tables 1 and 2

The data in Tables 1 and 2 is for illustrative purposes only. For comparative purposes and analysis, fan vendor A was selected from a group of three fan vendors all of whom had provided similar data. Fan vendor B stood out with quite different data.

The tables provide an organized opportunity to compare critical data regarding several proposals. The typical evaluation process would compare multiple operating duties.

It is important to note that when a fan vendor, such as B, has significantly different values for items such as losses, it is essential to check in detail with the fan vendor the reason for the differences. Furthermore, it is necessary when evaluating operating costs to look at all factors.

Many fans operate at highest efficiency when selected close to the peak of the fan curve. During the proposal evaluation, one should ensure that all fan vendors have selected the fans sufficiently below fan peak pressure.

A decision based solely on individual items, such as electrical input power, may be flawed. All items in the table should be considered with an appropriate weighting.

Initial Capital Cost

The initial capital cost tends to be the easiest cost to calculate and evaluate. When assessing the initial capital cost, it is important to consider not only the cost of equipment, such as fans, motors, drives, switchgear, controls, heater houses, enclosures, civil works, etc., but also the costs of installation and commissioning. The costs of installation and commissioning are a function of fan type, size, and layout. In addition, these costs are inversely proportional to the design features offered. Adding features, such as bearing pedestals, bearing pedestal soleplates, motor sole plates, motor bases, jacking features, bolted construction, machined impellers and inlet cones, machined blade tracks, impeller and blade setting tools, pre-wired junction boxes, pre-assembled lubrication piping, etc., adds to the equipment cost but can reduce installation and commissioning costs. The reduction in installation and commissioning costs invariably exceed the additional costs of such features.

Maintenance Costs

When specifying ventilation equipment, the future service and maintenance required is seldom considered. Yet, there are significant costs associated with maintaining large ventilation fans and associated equipment. The evaluation of expected maintenance costs is difficult at best. The best sources for estimates on potential maintenance costs are the mine's maintenance department and the fan vendors. Usually, the maintenance department is able to give good estimates on the time required to do specific tasks. The equipment suppliers are in a position to give detailed monthly, semi-annual, and annual service requirements. In addition, they are willing to give customers estimates on spare parts usage. However, the spare parts usage is a function of operating conditions.

On specialized new products, it is important to make sure that the vendor will guarantee the availability of spare parts and product support for the duration of the design life of the equipment. This has been an issue with some power plants who purchased earlier designs of variable frequency drives. They are finding it difficult to get spare parts and product support for these earlier designs. Some have been forced to replace their equipment prematurely.

Fan Reliability

Although fans and their associated ancillary equipment are not usually considered part of a mine's production equipment, their reliability can have an effect on a mine's production. Unless some type of reliability guarantee is specified in the proposal documents, it is very difficult to evaluate their reliability. Even with a reliability guarantee, the evaluation of a fan's reliability is still ultimately a judgement call. The real cost to the mine associated with a fan being unreliable will be considered to be a consequential cost by any fan vendor or equipment supplier. Very few, if any, fan vendors or equipment suppliers will accept consequential damages as part of their contract terms. One of the best ways to make this judgement call is to check references.

Operational Flexibility

Like any long-term plan, a mining plan can change over the expected life of the operation. Often, these changes may result in significant changes in ventilation requirements. Therefore, a degree of operational flexibility ought to be considered in the project.

However, besides this built-in flexibility, the overall operational flexibility should be evaluated. Areas that should be considered are the margin available on motor power, on operating pressure, and on volume flow. As a general rule, axial flow fans tend to have a higher degree of operational flexibility than fixed speed centrifugal fans.

Suggested Design and Construction Details

There are many relatively inexpensive features that can be designed into fans that significantly improve the life, ease of installation, or the maintainability of the equipment. Features add to the cost of equipment but reduce the cost of installation, maintenance costs, or improve the evaluation of the project, such as:

- Fan casing and ducting gauges—Under normal circumstances, the material cost component for these items is less than the labour. Often, using heavier gauges is cost-effective as it reduces the required amount of stiffening and bracing. It extends the life of the equipment. On large fan installation, fan casings should be no less than 8 mm and ducting no less than 6 mm.
- Bolted access doors—A feature that is relatively inexpensive but adds to the maintainability of the equipment is having raised access doors. This allows the fan designer to avoid the use of welded studs or captive nuts and use standard bolts. It allows for the easy replacement of worn fasteners.
- Fasteners—A feature that has little cost impact but adds to the maintainability of the equipment is the use of a large diameter fastener. The minimum fastener size should be 16 mm. Where at all practical, all threads should be coarse threads. Where there is moisture present, the use of stainless steel fasteners improves the maintainability of the equipment.
- Jacking and alignment bolts—The use of jacking and alignment bolts adds little to the cost of the equipment but reduces the cost of installation and improves the equipment's maintainability.
- Sole plates—Where motors and bearing pedestals are being bolted to concrete foundations, the use of sole plates significantly reduces the cost of installation and improves the equipment maintainability. This feature has a moderate cost impact.
- Bolted joints—The use of bolted joints can have a moderate impact on equipment cost but this type of joint avoids field welding and subsequent field painting. Bolted joints reduce the cost of installation and improve maintainability.
- Machined wheel tracks—On axial flow fans, this feature can have a moderate impact on equipment cost, however, this results in the assurance that, unless damaged during transportation, the wheel track will be round. It enables the blade tip clearances to be reasonable and even, and as a result, improve fan performance. It helps with alignment. This feature helps reduce installation costs.
- Machined inlet and inlet ring—On centrifugal fans, this feature can have a moderate impact on cost and ensures that the impeller runs true and that the inlet cone to impeller inlet clearance is reasonable and even. As a result, it improves the fan performance and helps with alignment. This feature helps reduce installation costs.

Vendor History and Experience

When selecting a vendor, a vendor's proven track record and experience in designing and building similar type equipment is important.

When evaluating their track record and experience, it is important to find out not only about projects that were executed without problems, but also to find out about projects on which problems were experienced. Any vendor who claims not to have experienced problems on projects is either guilty of misrepresentation or does not have the required experience. The issue is how one goes about resolving problems and how quickly one reacts. The issue is not about whether or not a vendor has experienced problems but rather about whether or not he resolves the problems. Does the history show that the vendor solves the problem or does he walk away from the problem? How quickly does he react?

Vendor Qualification

In this specialized field, the vendor qualification is an important step in the evaluation process. When qualifying a vendor, the following areas should be reviewed:

- sales support;
- design and engineering capabilities;
- manufacturing facilities;
- aftermarket capabilities and parts availability;
- quality assurance;
- financial strength and bonding capability;
- testing facilities; and
- history and experience.

Project and Equipment Evaluation

A comparison of the initial capital cost of equipment is only a very small part of the project evaluation. In fact, it is the easier part of the evaluation. To be sure that the correct decision is made, it is important to do a total evaluation. Each of the various topics discussed have differing degrees of importance. These degrees of importance not only vary from country to country but also from company to company and mine to mine. When evaluating a project, it is important to develop a weighting for the different topics discussed.

Acknowledgments

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Related publications and standards of the Air Movement and Control Association (AMCA), 30 West University Drive, Arlington Heights, Illinois, United States:

- AMCA Publication 201-85: Fans and Systems
- AMCA Publication 210-85: Laboratory Methods of Testing Fans for Rating
- AMCA Publication 802-92: Establishing Performance Using Laboratory Models
- AMCA Standard 803-87: Site Performance Test Standard