Surface fan operational cost saving using purposely designed fans

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ABSTRACT

The use of high powered catalogued auxiliary fans to meet the ventilation requirements of fairly shallow mines is common practice and often is not an energy efficient ventilation solution.

This paper describes the process followed to investigate the potential of using alternative and more energy efficient axial flow fans to meet the ventilation requirements when used as main surface fans for shallow platinum mine shafts.

The benefit of replacing catalogued auxiliary fans used as main fans with purposefully engineered fans was considered. From the investigation it can be concluded that the operational cost saving associated with the saving in power due to the improvement in the operational efficiency proved that the replacement of the older generation installations is viable.

When comparing a single original fan installation to a purposefully engineered fan it will have a payback period of approximately 7 months per complete new installation and will continue to save electrical operational cost as a result of the improved energy efficiency.

1. INTRODUCTION

In an effort to reduce operational costs associated with the ventilating of mines' improved energy efficient ventilation methods must be considered. In South Africa higher than inflationary electricity increases in recent years have increased the operational cost of mine ventilation and cooling. The use of high powered, often inefficient, auxiliary fans to meet the ventilation requirements increases the overall energy requirements of ventilation systems.

As a result of this, the need to identify these high powered auxiliary installations and to explore means to replace them with more energy inefficient operating units must be considered.

The main contributors to the low efficiency of some of the older generation fans are attributed to poor aerodynamic design, incorrect fan selection or the changes in the design to current day fan operating points due to changes in the mine's resistance.

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Therefore the selection of and the design of fans is critical to meet design performance requirements and energy consumption, keeping in mind the correct fan selection for the application. A well designed fan is required to improve the overall ventilation system efficiency, with the correct system considerations in the design process as it reduces wasted air power while enhancing system efficiency.

This paper describes the process considered to improve the operational efficiency of the current surface fan installations.

It includes the consideration to design and develop an alternative more energy-efficient axial flow fan with the ability to meet the requirements as main surface fans for the shallow platinum mine.

A brief overview of the results is given, including advanced technology design aspects, fan development and selection, conversion capital costs, payback period and expected energy saving.

2. BACKGROUND

In this section of the paper, the current fan installations were investigated to determine the baseline installation performance.

2.1. Contra-rotating dual stage 110 kW fan sets

The shallow platinum mine shafts investigated were ventilated by means of older generation 110 kW contra-rotating dual stage fan sets. Each of these 110 kW contra-rotating dual stage fan sets consist of 2 by 55 kW fan stages operating in opposite directions and installed in direct series (further referred to as the 110 kW fan). A photograph of one of these installations is shown in Figure 1.

Figure 1: Photograph showing current 110 kW fan installation

These robust fans are known for their ability to deliver a reasonable quantity of air at a relative high pressure loss. A total of 46 of these 110 kW fan sets were installed at the different shallow platinum mine shafts that formed part of this study.

In Table 1, the actual performance of the original 110 kW fan set as measured in a controlled environment (ISO 2008) is shown.

Table 1: Original fan performance

Description	Unit	Measurements
Average airflow quantity per fan set	m^3/s	24.5
Average Pressure loss	kPa	1.78
Power Consumption at duty	kW	115
Fan static efficiency at duty	%	37

3. NEW FAN DESIGN REQUIREMENTS

In an attempt to improve the energy usage and associated energy cost, companies were approached to design a fit for purpose fan solution. One of the fan supplier companies was approached by the mining house to assist in finding an appropriate technological solution. They identified a close fit to the design requirements with one of its standard 75 kW fan units. Further engineering development was needed to increase this unit's performance to meet the actual fan performance requirements of the shallow platinum shafts. This needed to be achieved in a more energy efficient manner. A minimum design quantity of 20 m^3/s was specified by the mine at a pressure of 2 kPa and the fan had to be able to handle higher pressures (of up to 2.5 kPa) if needed.

Advanced technology was applied such as a 3-D computer aided design (CAD) model, computational fluid dynamics (CFD) analysis and finite element analysis (FEA) for the stressing of the structure (du Plessis, Ratner and Viviers, 2015). Aspects such as aerodynamics, mechanical elements, stresses and vibration were considered and addressed in the design and manufacture of the fan. In the sections that follow a brief overview of these aspects are discussed.

3.1. Aerodynamics

The aerodynamic characteristics of fan blades depend strongly on the shape of the blade, as the "aerodynamic profile" of the blade is decisive when it comes to blade performance and efficiency. Even minor alterations to the shape of the profile can greatly alter the power and noise levels. Therefore, in order to obtain maximum aerodynamic efficiency, it is essential to choose an appropriate shape with great care.

Higher efficiencies in an axial flow fan can be achieved if the rotor blades are profiled and have certain twist. Aerodynamic profiles have better lift-to-drag ratios than cambered plates and hence reduce the drag on the rotor, thereby reducing the power required.

A 3-D CAD model is generated and a CFD analysis is performed to verify the design. CFD analyses are performed for different flow rates to determine whether the design matches the fan design requirements.

3.2. Mechanical design

Aerodynamic improvement is not the only important factor to be considered in the design and development of fans as the use of improved materials and advanced mechanical design techniques also contribute significantly to the design and development of a fan.

In conventional aluminium alloy bladed mine fans, their cross-section barely matches a suitable aerofoil geometry that can develop sufficient lift and minimal drag forces. Furthermore, the roughness of the blade surface considerably increases the losses.

Un-machined cast iron blades give an efficiency that is approximately 10% lower than that of machined blades. Hence, careful smoothing of the blade surfaces is essential to obtain better fan efficiency.

Lastly, a mechanically well-designed fan should not vibrate excessively and should be able to overcome any stress on the material used to make the fans. A number of mechanical design issues have been considered in the design of the fan, resulting in a fan that is both more efficient and more robust, and that will hence have a longer mean time between failures.

3.3. Stress analysis of the rotor

A FEA was performed to determine whether the blade root attachment was sufficiently strong. Only centrifugal loading was considered as it is by far the greatest load. An FEA model analysis was also performed.

This is the study of the dynamic properties of structures, in this case the rotor assembly under vibration excitation. This is done to ensure that the rotor natural frequencies do not overlap with the operating frequencies. The analysis was performed for both the stationary and operating loading conditions of the rotor assembly.

3.4. Designing for reduced vibrations

Vibrations arising from imbalance of the rotor can be reduced by carefully balancing the rotor. The rotors were dynamically balanced by using a balancing rig. The design criterion was to meet vibration levels of at least 1 mm/s or less. From the originally designed fan, it was, however found that despite having a well-balanced rotor, vibrations in the axial direction remained high.

The general standard practice was always to attach the fan motor to the barrel by means of tie rotor webs. Tie rod supports provide stiffness in the radial direction, but limited stiffness in the axial direction.

By replacing the tie rod with a strut arrangement, the stiffness in the axial direction is improved resulting in reducing vibrations in the axial direction. An additional benefit is that the motor assembly time and motor maintenance time are reduced. Typical vibration measurements for the strut assembly are generally below 0.5 mm/s with motors attached by this method.

4. NEW GENERATION 75 KW FAN

The selected fan supplier designed a 9-blade impellor driven by a 2-pole (3000 rpm) 75 kW motor fan.

The performance and efficiency of the new generation fan performance was measured in a test duct (ISO 2008) and the performance seemed to be in line with the requirements as shown in Table 2.

Table 2: New fan performance

Description	Unit	Quantity
Quantity	m^3/s	22.5
Average Pressure loss	kPa	2.20
Power Consumption at duty	kW	75
Fan efficiency at duty	%	66

Two of the new fans were installed at a new installation at one of the shallow platinum mine shafts where it was trailed and tested under normal operational conditions. The performance confirmed the applicability for the designed purpose as surface fans for the shallow platinum mine shafts.

Figure 2: Photograph showing new fan installation

The evaluation of and the results of the original fan installations with the new generation fans compared favourably with the previously installed 110 kW fan sets and the measured results are shown in Table 3. The new fans deliver an airflow quantity of between 22 and 23 m^3/s at a measured pressure of 2.2 kPa as per the original design.

4.1. Fan selection

Table 3: Comparison of old and new fan performance

Fan	Position	Type of fans	Pressure (Pa)	Volume (m^3/s)
Fan 1 - W 67	E3	110 kW	1 540	26.7
Fan 2 - W 67	E3	110 kW	1 480	28.4
Fan 1 - CNRL	E3	110 kW	1 940	24.6
Fan 2 - CNRL	E3	110 kW	2 160	25.4
Fan 1 - E71	E3	110 kW	1 560	24.1
Fan 2 - E71	E3	110 kW	1 900	22.5
Fan - E71	E3	110 kW	1 620	22.3
Fan 1 - 5	E 58	5 E 75 kW	2 200	23.0
Fan 2 – 5	E 58	5 E 75 kW	2 200	22.1

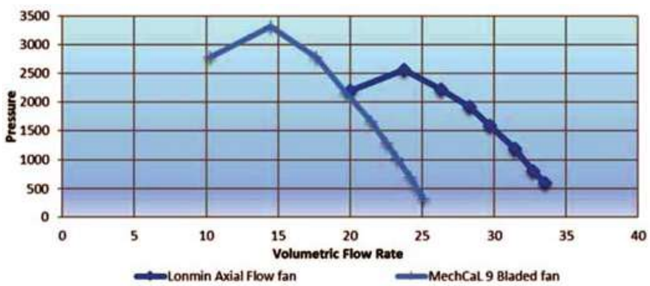

Figure 3: Fan curves showing difference between current and the new fan installation

The fan performance graph (shown in Figure 3) illustrates the ability and flexibility of the new generation fan as it is able to handle pressures of up to 3.2 kPa. This supports appropriateness for the application in shallow platinum mines as one of the design requirements were that the fans needed to be able to operate at higher pressures.

From Table 3 the older generation fan performs better with regards to volumetric flow delivery at the lower pressures.

When the efficiency of the fans is compared (as shown in Figure 4), the difference in the fan efficiency at the desired operating point of 20 to 22 m^3/s is observed. This observation confirms the importance and appropriateness of the correct fan selection for a specific application.

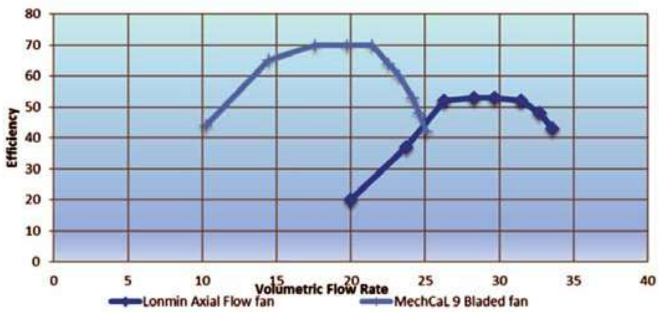

Figure 4: Fan total efficiency curves

4.2. Conversion and replacement

As the fan stations already exist, the new fan installations had to be manufactured to be fit for purpose.

Figure 5: Picture of developed fan showing diffusers

For the ease of installation, the new fans were supplied with pre-manufactured and specifically designed diffusers and reducers (1 016 mm compared to the 1 200 mm of the 110 kW fans). This enabled direct retro-fitment as it was fabricated to fit directly into the position of the larger 1 200 mm ducting from the original 110 kW installations.

4.3. Cost Comparison

In Figure 6 the difference in annual running cost (only electrical cost based) between a single installation of the original fan when compared to a new generation fan installation is shown graphically.

The running cost was calculated using the absorbed power at duty as shown in Tables 1 and 2 and assuming an all year round operation (8760 hours per year).

Figure 6: Comparison of single fan installation annual running cost

The payback period for the replacement of catalogued auxiliary fans with purposefully engineered fans was calculated to be approximately 7 months.

5. CONCLUSION

In this paper, the benefit of replacing catalogued auxiliary fans used as main fans with purposefully engineered main fans was considered. From the investigation it can be concluded that the operational cost saving associated with the saving of power cost due to the improvement in the operational efficiency is viable.

When comparing a single original fan installation

it will have a payback period of approximately 7 months per complete new installation and will continue to save electrical operational cost as a result of the improved energy efficiency.

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