The use of simulations to identify operational improvements on mining compressed air systems

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It all starts here ™

Abstract

Title:	The use of simulations to identify operational improvements on mining compressed air systems
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As operational costs of deep level mines increases and gold ore grades decrease, profitability in the gold mining sector is becoming a challenge. Electricity tariff increases have contributed to a rise in the cost of operating mines. Compressed air systems are utilised on mines as they provide safe, reliable power for various underground machines. Compressed air is also used for emergency oxygen in refuge bays.

Compressed air systems utilise a significant portion of a mine's total energy. It has been shown that many deep level mine compressed air networks have inefficiencies. Improving the efficiency of these systems could result in a reduction of operational costs by reducing the energy required to produce compressed air. Additionally, an improvement in service delivery could be achieved.

Previous studies have shown the usefulness of simulations to develop improvements for deep level mining systems. However, these studies have not followed a structured methodology for developing compressed air simulation for deep level mines. Previous studies have also simplified compressed air models reducing the simulation precision and testable scenarios.

In this study a simulation methodology was therefore developed. Investigations into the compressed air systems are performed. A model is then developed in software to accurately recreate the system operation. Finally a proposed means of improvement is simulated, analysed and quantified in terms of improvements in energy savings and service delivery.

Two case studies were evaluated. For each case study a variety of scenarios were simulated. In case study A by reducing air used by refuge bays in simulation, a reduction of 1 MW E.E. would be achieved with addition to a significant improvement of 18 kPa to system pressure. Drop tests implemented on the case studies validated the simulation with a precision of 5%.

The study showed that simulation is a important tool for identification improvements in large compressed air systems. By utilising a structured methodology to develop detailed compressed air simulations, inefficiencies and operational improvements were identified.

Keywords: Mining, Energy, Compressed air, modelling, Simulation, operational improvements

Contents

Abbreviations

CALDS Compressed Air Leakage Documentation System.

DSM Demand Side Management.

PLC Programmable logic controller.

SCADA Supervisory control and data acquisition.

STB Simulation Toolbox.

THS Thermal-hydraulic simulation.

Nomenclature

kPa - Kilopascal.

MW - MegaWatt.

T - Tonne.

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CHAPTER 1

Introduction and background

"*Quote.*" - Somebody

1.1 Preamble

This chapter firstly discusses background regarding deep level mining in South Africa. Next, the need to reduce costs of operation in the mining sector is examined. From this a focus in reducing energy consumption of compressed air systems is developed. Next, background on compressed air operation and energy interventions are discussed. Simulations and their value in industry is discussed leading to a problem statement and objectives of the study. Finally, an overview for the dissertation is provided.

1.2 Background on deep level mining

1.2.1 Mining profitability

Various technical, economic, social and operational challenges are posing a risk to the profitability of the South African mining sector. One of the challenges the sector faces is a rise in the cost of operation [1].

A considerable factor that is contributing to the rise of operational costs in South African gold mines has been the increase in electricity costs. As shown in figure 1.1, the general cost of electricity has increased at a rate greater than inflation since 2008 [2].

In addition to rising electricity costs, gold ore grades of South African mines have fallen substantially over the last few decades [3]. As ore grades decline, the energy utilised per unit of metal increases exponentially [4]. Therefore mines require significantly more energy per unit of metal produced. This combination of tariff increases and increased energy usage per unit have led to significant rises in mining operation costs.

1.2.2 Process of a deep level mine

`Brief description of the mining process`

[1] inflation.eu, "Historic inflation South Africa - cpi inflation." [Online] `http://www.inflation.eu/inflation-rates/south-africa/historic-inflation/cpi-inflation-south-africa.aspx`, [Accessed 25 March 2017].

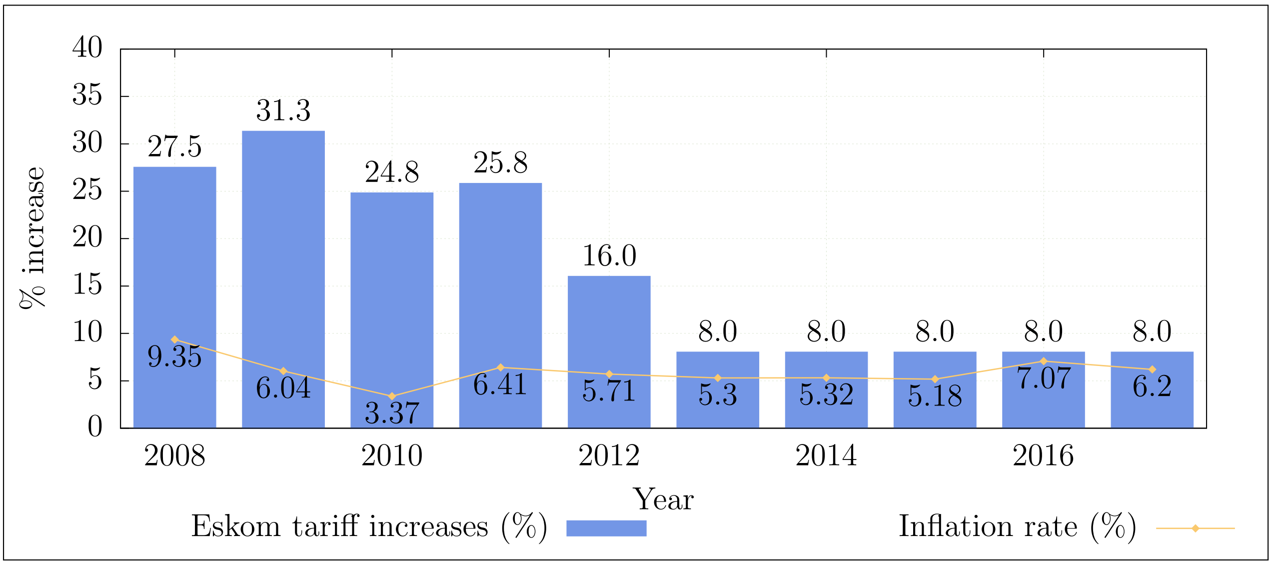

Figure 1.1: Electricity price increases between 2007 and 2017 [2] compared to the inflation rate in South Africa.[1]

1.2.3 Mining Services

Energy usage

The mining industry uses extensive amounts of energy. In South Africa, the industry utilizes approximately 15% of the national electricity supplier's yearly output, of which, gold and platinum mines use 80%.[5]

Figure 1.2 shows the division of energy within the mining industry. The chart shows that compressed air systems utilises the most energy within a mining industry. It is reasoned that energy can be most effectively reduced through the implementation of energy interventions on compressed air systems.

1.3 Compressed air systems in mining

1.3.1 Compressed air in operation

Largely due to their reliability, versatilely and ease of use, the South African mining industry has installed extensive compressed air networks. These systems can have compressors with capacities of up to 15 MW [7].However, the supply of compressed air is a highly energy demanding and costly process [8]. The energy used for compressed air production contributes

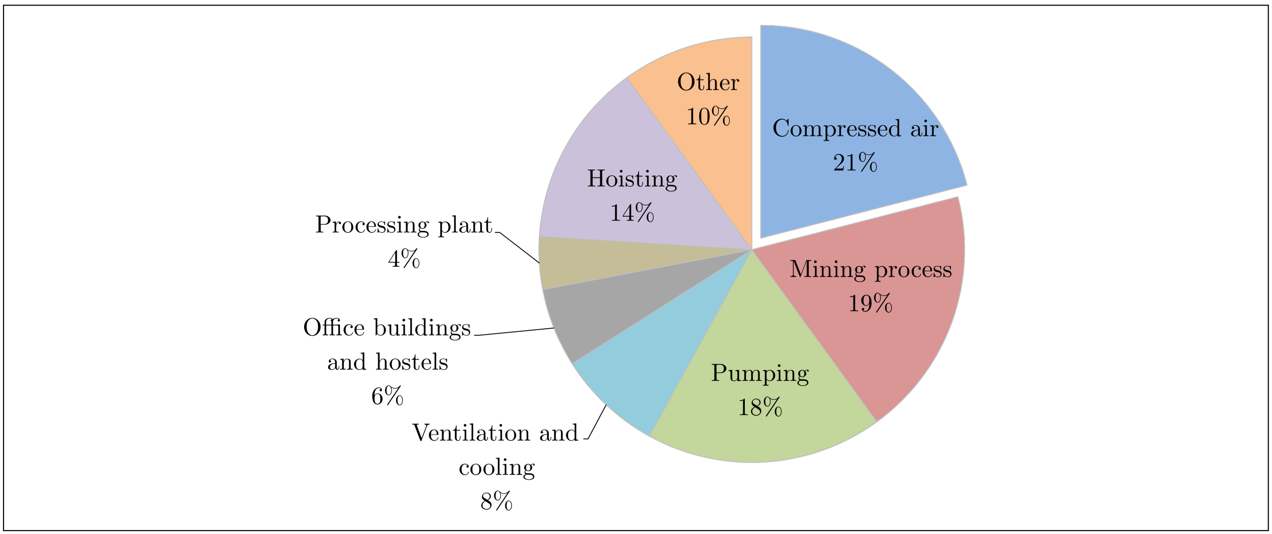

Figure 1.2: The energy consumption for each mining system [6].

to between 9% and 20% of the total mining energy consumption [5],[9].

Large compressed air systems are likely inefficient. Internationally, the expected energy savings potential of a large compressed air network is 15% [10]. Marais [11] showed that energy savings of up to 30% and 40% can be attained through various interventions.

Pneumatic rock drills

Drilling is mainly performed in the production areas or stopes of a mine. Drill machines are used to drill holes into the rock face. Once the holes have been drilled, explosives are then installed to break up the rock [12].

Compressed air is used to power pneumatic rock drills within a mine. Pneumatic rock drills run at an efficiency of 2%. This is low when compared to alternative rock drills such as electric, oil electro-hydraulic and hydro-powered drills that run at an efficiency of between 20-31% [13],[14].

Refuge bays

Refuge bays are installed in mines to provide safety to miners during emergencies. Most mines will utilise compressed air to deliver safe, cool air to the refuge bay. The provision of 1.42 l/s of air per person at a pressure between 200 and 300 kPa is required to provide oxygen and prevent any poisonousness gas entering the refuge [15].

Airflow in the refuge bays can be controlled with a manual valve within the chamber. Any many cases, this valve is often misused by mine workers who open the valves fully in order to cool the bay through the decompression of the air. `*** need source ***`

Compressed air control

On many large compressed air networks, the intake guide vain position on a compressor is manipulated in order to obtain the air flow and pressure requirements. Typically, guide vains are opened and closed to increase and decrease the compressors discharge pressure. When more pressure is required than can be obtained with the guide vains fully opened, another compressor is needed to operate.

As shown in the figure 1.3, showing guide vain positions vs power for a typical mining compressor, the guide vains are controlled between 40% and 100% of their fully open position. Reducing and increasing the guide vain position will effect the power output of the compressor.The relationship between power and guide vain position of a compressor can be approximated as a linear function. A guide vain position of 40% will relate to an output power of about 60% of maximum power.

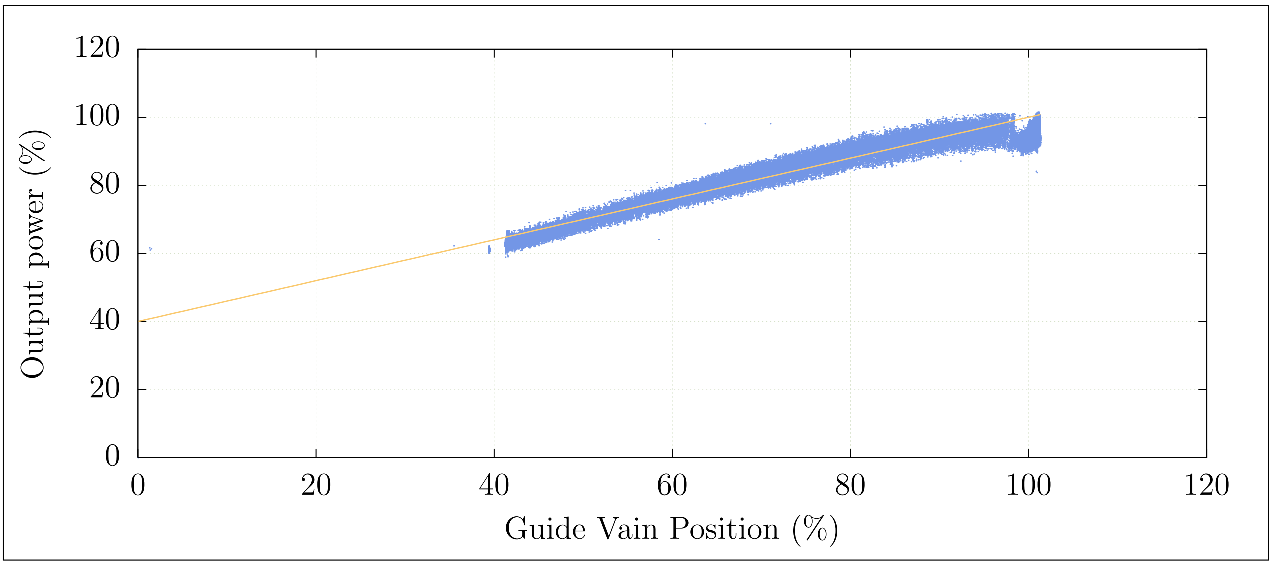

Figure 1.3: The relation between guide vain position and compressor output power.

Operation schedule

On a typical mine, various operations will take place at different times of the day. Depending on the activity taking place, many mines will control the pressure to meet the requirements [16],[7]. Figure 1.4 shows the schedule and pressure requirement on a typical deep level mine.

As shown in the figure, the pressure requirement changes depending on the activity taking place. The drilling shift typically has the highest pressure requirement whilst blasting shift requires the lowest. Schedules and operation philosophies can differ between mines. Different operational schedules require alternative pressure requirement profiles.

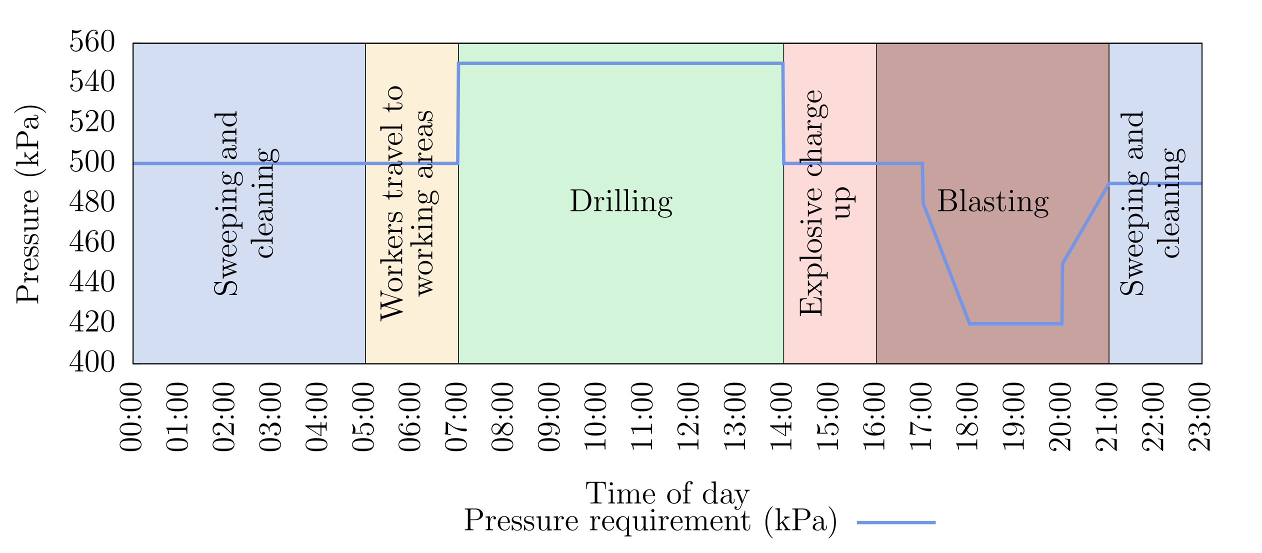

Figure 1.4: The typical operation schedule of a deep level mine [16].

1.3.2 Characteristic inefficiencies of compressed air systems

Compressed air distribution networks in the mining industry consist of multiple compressors and working areas up to eight kilometres away from the source [7]. Due to their size and complexity, these systems are prone to large energy losses.

Compressed air leakage accounts for as much as 35% of the energy losses of a compressed air network [17]. Other systemic losses include, faulty valves, pipe diameter fluctuations, obstructed air compressor intake filters and inefficient compressors.

1.3.3 Instrumentation and measurements

For large industrial systems, thorough instrumentation is necessary in order to monitor performance and condition throughout the system. In a mining compressed air network, instrumentation is installed on the compressor to monitor flows, pressures, temperatures and guide vain position. Electrical instrumentation is also installed for sensing currents, power factors, voltages and power. On control valves, input/output pressures, flows and valve position are usually measured with instrumentation.

Programmable logic controllers (PLCs). A Supervisory control and data acquisition (SCADA) system is is used to observe and monitor all of the instrumentation.

When instrumentation is not installed. Manual measurements are performed.

`Not finnished`

1.3.4 Inefficiency identification methods

Leakage and inefficiency detection strategies is not often pursued in the South African mining industry [14]. Many mines do however perform leak inspections either internally or by a outside company. In these inspections, an ultrasonic detector is used to locate the leak. Alternatively, some mines employ the 'walk and listen' method to identify leaks from the audible sound that it produces [14]. Once the inspection is completed, the findings, including the locations and estimated costs of all identified leaks, are reported. `Need to added a citation or two`

1.3.5 Compressed air savings strategies

The main strategies fo reducing energy on compressed air systems are summarised as follows [18]:

- Reducing leaks.
- Reducing demand.
- Reducing unauthorised usage.
- Increasing supply efficiency.
- Optimising supply.

`Still need to discuss more detailed`

1.4 Simulations

1.4.1 Background in industrial simulation

Continuous improvements in computing hardware has led to major advancement in software technology. Consequently the use of computational simulation has become an increasingly valuable tool for many industries.[19]

In *Handbook of simulation: principles, methodology, advances, applications, and practice*, the advantages of the use of simulation in industry are discussed as follows [20]:

- The ability to test new policies, operating procedures and methods without causing a disruption to the actual system.
- The means to identify problems in complex systems by gathering insight in the interactions within the system.
- The facility to compress or expand time to investigate phenomena thoroughly.
- The capability to determine the limits and constraints within a system.
- The potential to build consensus with regard to proposed designs or modifications.

1.4.2 Thermal-hydraulic simulation

Thermal-hydraulic simulation (THS) is the modelling and computational analysis of Thermal-hydraulic systems. THS models can be developed large mining systems such as cooling, compressed air water reticulation etc. In industry, various THS software packages are used for modelling and simulating these systems. Two such packages discussed in this dissertation are KY-pipe and Simulation Toolbox.

1.4.3 Use of simulation in mining

In industry, simulations have mainly been used as an initial verification of Demand Side Management (DSM) energy intervention proposals [16]. This removes potential risks that would arise from testing the interventions on the actual mining systems. However these simulations are typically highly simplified models [11].

1.5 Problem statement and objectives

1.5.1 Problem statement

Rising costs and falling ore grades are driving in the mining industry to reduce operational inefficiencies. Large energy savings can be made in Compressed air systems in the mining industry. However manual testing of interventions can be cumbersome.

Computer modelling and simulation of compressed air systems can be used to quantify and prioritise operational interventions that improve efficiency. The simulations would allow scenarios to be evaluated with minimal risk.

1.5.2 Research objectives

The main objective of this dissertation is achieve energy savings and identify operational improvements in mining compressed air systems. A simulation process to will be developed to achieve this goal.

1.6 Dissertation overview

`Describe (in approximately one sentence each) the contents of each of the dissertation chapters. No results here.`

CHAPTER 2

Literature study

"*Quote.*" - Somebody

2.1 Introduction

2.2 Methods to identify operational improvements

2.2.1 Preamble

2.2.2 Identifying areas for improvement

(Kriel Masters) -Investigation

-Measurements

-Simulated impact of the proposed intervention

2.2.3 Measurements

2.2.4 Leakage detection

(Van Tonder masters) - Inspections

- Audible sounds (by ear)

- Ultrasonic

- Intelligent leakage detection (instrumentaion SCADA)

- Alternatives (pigging, soap water, Dyes load/unload test)

- CALDS (Compressed air leakage document system)

2.2.5 Estimation techniques

- Snyman estimated improvements using historical data.[18]

- Marais estimation through simplified estimation, simulation [7, 11].

2.2.6 Summary

2.3 Review of compressed air energy interventions in industry

2.3.1 Preamble

(Kriel Masters) - Supply and demand strategies (improving compressor efficiency vs reducing/improving demand)

Marais et al investigated increased energy savings through the use of Compressed Air Leakage Documentation System (CALDS) [21].

2.3.2 Strategies to improve compressed air supply

- Control Strategies
- Relocating compressor. reconfiguring networks - Bredenkamp
- Compressor schedules
- Variable speed drives
- Compressor selection
- Marais showed compressed air saving potential through an expert control system.[22]

2.3.3 Strategies to reduce/optimise compressed air consumption

- Reducing leaks
- Control Valves - Pascoe
- Marais PhD

- Snyman - investigated various Compressed air demand reduction and efficiency optimisations [18].

Pneumatic rock drills efficiency

Reduced pressure to the drill will cause it to run even less efficiently. A study by Bester *et* *al.* showed that between 2002 and 2013 compressed air and energy consumption per tonne of ore produced had steadily increased as shown in figure 2.1. The increase in consumption per T was a result of a reduction in air pressure at the mining stopes. Measurements indicated that the pressure was as low as 300 kPa. This reduced the efficiency of the rock drills. Before 2002 pressure was maintained above 500 kPa at the stopes. .[23]

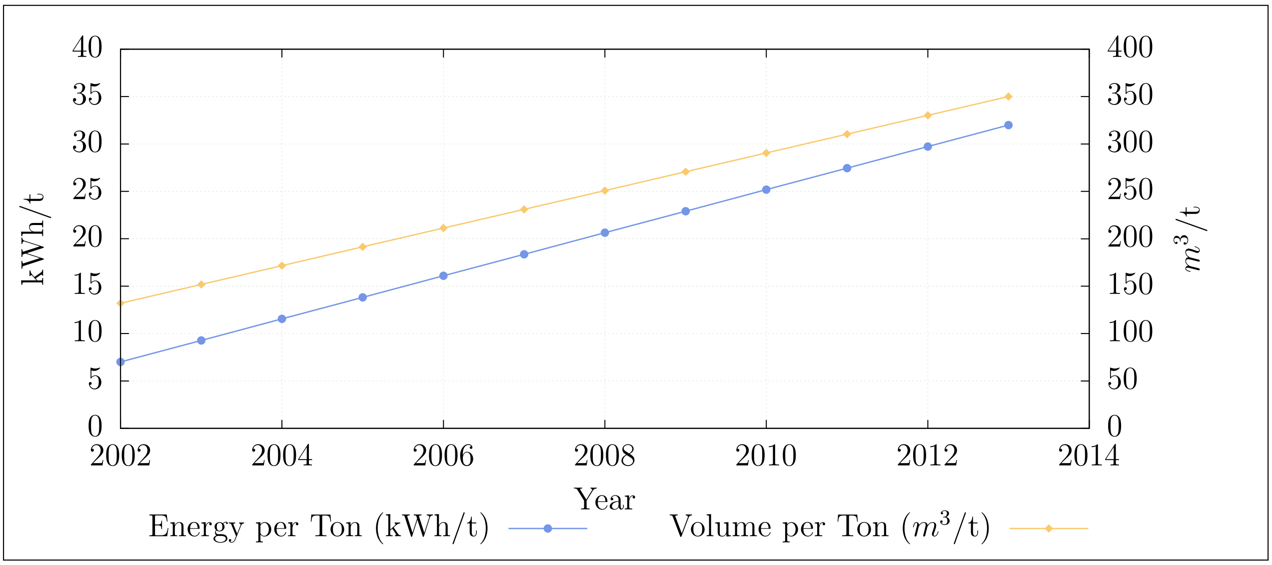

Figure 2.1: The Compressed air energy and flow consumed per T of ore produced. Adopted from Bester *et al.* [23].

2.3.4 Summary

2.4 Use of simulations to identify improvements in mining systems

2.4.1 Preamble

2.4.2 Value of simulation in DSM projects

(Van Niekerk M)

- Compressed air

- Cooling systems

- Dewatering

- Design optimisations using simulation

- KYPipe's gas simulation engine

- De Coning - simulations to investigate the opportunity to optimise the control strategy of a compressed air network by rescheduling the compressors.

2.4.3 Simulation procedures

-Kriel masters

-Pascoe

Periodic simulation

2.4.4 Verifying simulations

- Holman - van Niekerk masters

- Kriel masters (validation)

- Calibrating -pascoe - determining accuracy - pascoe - Du2015Development - comparisons with models - comparison with actual - First principles

2.4.5 Shortcoming of previous studies

2.4.6 Summary

2.5 Conclusion

CHAPTER 3

Developing a simulation methodology

"*Quote.*" - Somebody

3.1 Introduction

3.2 System investigation method

3.2.1 Preamble

Developing a detailed simulation model of a compressed air network requires thorough comprehension of the inner workings of the system. This section will discuss the investigations required to obtain this understanding.

3.2.2 Data acquisition and verification

- Layouts, data from SCADA Instrumentation, etc.

- Verification of accurate data - Gous article+

3.2.3 Solutions to unavailable data

Parameters that are required to develop the simulation model, such as flows, pressures, may not be actively logged by mine systems. To obtain this data it is necessary to investigate alternative sources. At points where instrumentation is absent, estimations can be made from assumptions made using instrumentation on the network or spot inspections.

Air network specifications such as piping sizes, technical layouts, major leak locations or specifications is often outdated or not recorded. Critical data should be obtained through audits and inspections of the system. If manual inspection is not possible, estimations should be made using the available data or approximation techniques discussed in literature. `REMEMBER TO REFERENCE SPECIFIC LOCATION LITERATURE`.

3.2.4 Mining schedule

A crucial aspect to developing an accurate representation of a mining compressed air system is understanding the the operational philosophy of the mine. The schedule for operations such as drilling or blasting can have a major impact on compressed air requirements throughout the day. Utilising the operational schedule, simulation scenarios can be optimised for the air requirements throughout the day.

3.2.5 Summary

3.3 Model development and verification

3.3.1 Preamble

This section will discuss the development of a compressed air simulation model in STB.

3.3.2 Compressed air component models

STB

Pipes

Ambient conditions

Ambient air condition will vary greatly throughout a mining air network. Pressure and temperature increases with depth as a result of auto compression. Underground conditions maintain relatively stable compared to the surface. Air condition can effect the performance of the network therefore it is important to include them in the model.

Surface conditions can be obtained through average weather measurements taken near or at the required site or estimated from measurements at other location. Underground conditions can be obtained through measurements if available. Alternative the conditions can be estimated by using the depth below the surface. The obtained pressure, temperature and humidity parameters can be imported directly into the air boundary component.

Compressor model

In STB three compressor models are available with varying complexity: air compressor, dynamic compressor and positive displacement compressor. When used, the compressor component is added to the air network in the arrangement shown in figure 3.1. The Compressor is connected to the inlet air source via an inlet pipe and air node and to the rest of the network via an air node and outlet pipe. This is is to allow the inlet and outlet parameters and conditions to be be monitored and controlled.

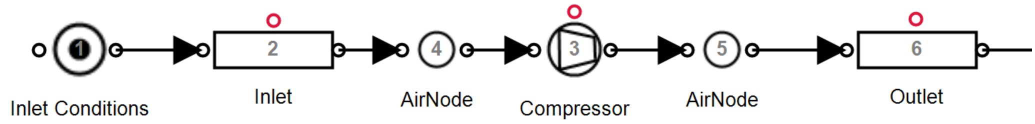

Figure 3.1: Modelling a compressor in STB.

The air compressor model is a general, simplified compressor model. This model requires minimal user inputs by making several assumptions. This is useful when parameters for a compressor are not available. Or when doing a quick preliminary simulation. However it is not ideal for detailed simulations which require more precision.

The dynamic and positive displacement compressor models are more complex, taking into account factors such as heat caused by polytopic compression and inefficiencies. The models do still make several assumptions for example, the compressor efficiency at different loads is assumed to remain the same. This can cause the operation of the model can differ slightly from the real life compressor.

For most scenarios, the dynamic compressor model will be suitable. This models fits a quadratic curve through three points to obtain an equation for corrected mass flow as a function of the pressure ratio. This characteristic compressor curve as shown in figure 3.2 can be accurately estimated even when only one data point is available by making approximations for the zero flow and pressure points on the curve.[1]

[1]TEMM International, "Process toolbox - Thermal hydraulic simulation flow solver," User Manual, 2014

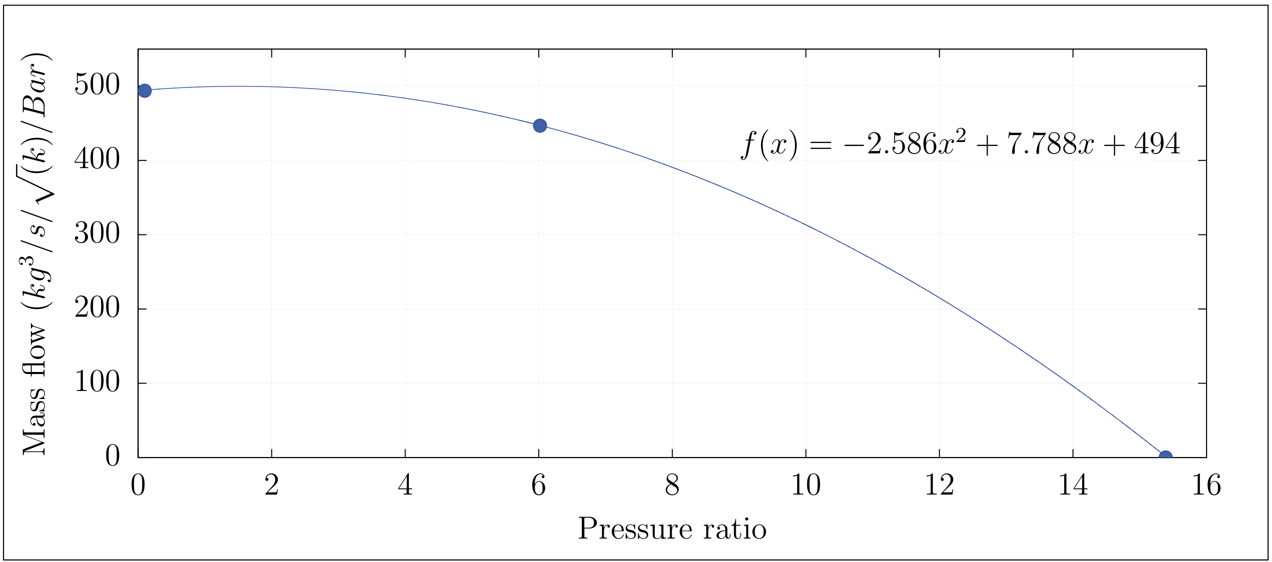

Figure 3.2: Estimating the characteristic curve of a compressor using the dynamic compressor model.

Demand/leak

Controllers

Compressed air networks rely on controllers

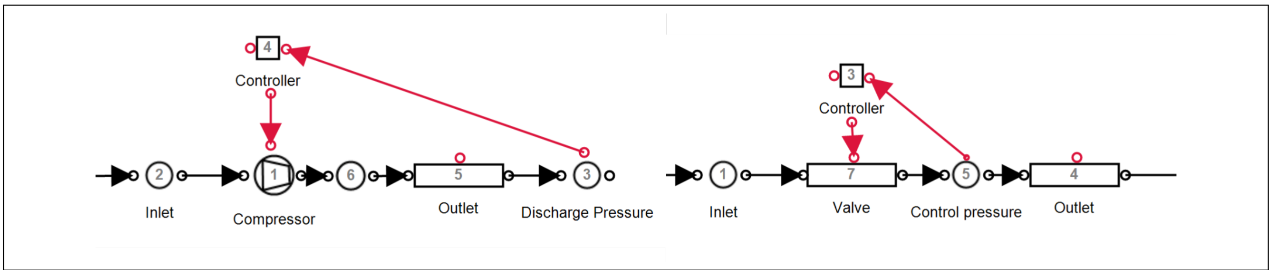

Figure 3.3: Control components in STB.

After Cooling

3.3.3 Simulation inputs

-Discuss inputs of the simulation, (compressor setpoints, ambient conditions, demands)

3.3.4 Verification of simulation model

- Steps to validate the model accuracy .

- Compare parameters to actuals

3.3.5 Summary

3.4 Approach to method implementation

3.4.1 Preamble

- This section will discuss the approach to implementation and analysis of the simulation.

3.4.2 Analyses of data

- Baseline vs Optimised comparison

3.4.3 Quantifying operational improvements

- Estimating cost savings

3.4.4 Summary

3.5 Conclusion

CHAPTER 4

Results and validation

"*Quote.*" - Somebody

4.1 Preamble

4.2 Case study: Mine A (Kusasalethu)

4.2.1 Background

4.2.2 Scenario 1. Refuge bay simulation

Tested scenario where all excessive leaking valves are removed. refuge bays savings 1MW E.E.

4.2.3 Scenario 2. Closing off levels/stopes

4.2.4 Summary

4.3 Case study: Mine B (Beatrix 123)

4.3.1 Background

4.3.2 Scenario 1. Compressor set points

4.3.3 Scenario 2. Control valves set points

4.3.4 Summary

4.4 Periodic simulation analysis

4.5 Validation of results

4.6 Conclusion

CHAPTER 5

Conclusion

"*Quote.*" - Somebody

5.1 Conclusion

5.2 Limits of this study

5.3 Recommendations for future studies

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APPENDIX A

1

APPENDIX B

2