OPTIMISING SHAFT PRESSURE LOSSES THROUGH COMPUTATIONAL FLUID DYNAMIC MODELLING

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DEPARTMENT OF MINING ENGINEERING

UNIVERSITY OF PRETORIA

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William James Kempson

Dated this 5th day of March 2012

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ABSTRACT

Optimising Shaft Pressure Losses Through Computational Fluid Dynamic Modelling

WJ Kempson

Supervisor:	Professor R.C.W. Webber-Youngman
Co-Supervisor:	Professor Josua P Meyer
Department:	Mining Engineering
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As a result of the rising electrical energy costs in South Africa, a method was sought to reduce the overall electrical consumption of typical shaft systems. A typical shaft configuration was analysed and the primary energy consumers were identified. The ventilation fans for this system were found to consume a total of 15% of the total energy of the shaft system. It was calculated that more than 50% of this energy is consumed by the shaft itself, more specifically by the pressure losses that occur in the shaft as the ventilation air passes through it.

It was recognised that there was therefore an opportunity to achieve an energy savings and therefore a costs savings in the total cost of operating a shaft system by reducing the overall resistance of the equipped downcast shaft. However, before any work could continue in this regard, the results noted above required validation. This was achieved though the comprehensive evaluation of the Impala #14 Shaft system. This system was tested and the pressure losses noted in the calculations were verified.

In order to ensure that the theory being used was accurate, the next step was to evaluate a number of shafts both from a theoretical perspective by measuring the real shaft pressure losses against time. This was done and a total of five shafts were instrumented and the actual pressure losses over the shaft plotted against time. These shafts were then subjected to a theoretical evaluation using the theory as described by McPherson in 1987.

Finally, in order to ensure a thorough understanding of the behaviour of the ventilation air in shaft systems, the systems were simulated using computational fluid dynamic (CFD) techniques.

On the whole there was not a good correlation between the tests and either the theoretical calculations or the

CFD simulations. This was attributed to the general imperfections in the shaft and the difficulty in obtaining exact values for the drag coefficients of the buntons. These differences highlight the difficulty in modelling the non-homogenous physical environment and providing a factor that can be used to ensure that the theoretical designs are aligned with the physical reality. This factor is approximately 30%.

There were also significant discrepancies between the theoretical analysis and the CFD simulation during the initial comparisons. This discrepancy reduced as the complexity of the CFD models increased, until, when the complete shaft was modelled using the full buntons sets, the pipes and the flanges, the difference between the theoretical evaluation and the CFD simulation was small.

This result demonstrates that the theory is insufficient and that the inter-related effect of the buntons and fittings has not been fully appreciated. The current theory however has been developed using drag coefficients and interference factors for the buntons sets which have been taken from measurements of similar configurations. This does account for the relative accuracy of the current theory in that there is little difference between the CFD result and that of the theory. However, as the shaft parameters are changed to reflect new layouts and scenarios, it is unlikely that theory will continue to prove accurate.

The final phase of the work presented here was to evaluate the cost-effectiveness of using different bunton shapes and shaft configurations. It is shown that:

- The increase in the pressure losses and therefore the direct operating costs of the shaft can vary by as much as 80%, depending on the bunton configuration chosen.
- The placement of the piping in the shaft can increase the pressure losses and therefore the direct operating costs of the shaft by as much as 12%, depending on the placement of the piping in the shaft; this effect includes the use of flanges.
- The use of fairings on a large cage can reduce the resistance that the cage offers to the ventilation flow by as much as 30%. This, however, does not translate into a direct saving because as the cage moves through the shaft, the overall effect is transitory.

The savings discussed above can be significant when the items highlighted in this work are applied correctly.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

μ	kg/(ms)	$lb.s/ft^2$	slugs/fts	Absolute/dynamic viscosity of air
A_{B1}	m^2	ft^2		Frontal area of buntons
A_{B2}	m^2	ft^2		Frontal area of secondary buntons
A_{B3}	m^2	ft^2		Frontal area of tertiary buntons
A_{BF}	m^2	ft^2		Total frontal area of all buntons
$A_{CS\ Shaft}$	m^2	ft^2		Cross -sectional area of shaft
A_{FS}	m^2	ft^2		Free cross-sectional area of shaft
A_{Conv}	m^2	ft^2		Frontal cross-sectional area of the conveyance
BC	m			Below collar
BIC	-			Bushveld Igneous Complex
BS	m	ft		Spacing between buntons
C_D	-			Coefficient of drag
C_{D1}	-			Coefficient of drag for the primary buntons
C_{D2}	-			Coefficient of drag for the secondary buntons
C_{D3}	-			Coefficient of drag for the tertiary buntons
C_{DF}				Final coefficient of drag, average on total frontal area contribution
C_f	-			Coefficient of fill
c_p	J/(kgK)			Specific heat at constant pressure
CPI	-			Consumer Price Index
DN	-			Diameter nominal (of pipe)

DSM	-		Demand side management
$E_{l\ (meas)}$	J/kg		Energy loss (based on measured data)
f	-		Chezy-Darcy Friction factor
f_{B1}			Chezy-Darcy Frictional resistance of the bunton set 1 (primary bun tons set)
f_{B2}			Chezy-Darcy Frictional resistance of the bunton set 2 (secondary bunton set)
f_{B3}			Chezy-Darcy Frictional resistance of the bunton set 3 (tertiary bunton set)
f_{BTotal}			Chezy-Darcy Overall frictional resistance of the bunton sets
f_{Shaft}			Chezy-Darcy Friction factor of the shaft
f_{Total}			Chezy-Darcy Total friction factor of the shaft
G	kg/s		Mass flow rate
g	m/s^2		Gravitational constant
GDP	-		Gross Domestic Product
H	m		Height
h_{ai}	J/kg		Enthalpy of dry air (inlet)
h_{ao}	J/kg		Enthalpy of dry air (outlet)
h'_{wi}	J/kg		Enthalpy of water vapour
h'_{wl}	J/kg		Enthalpy of liquid water
h'_{wo}	J/kg		Enthalpy of water vapour
k	kg/m^3	Ns^2/m^4	Atkinson friction factor

$k_{Buntons\ Total}$	kg/m^3	Ns^2/m^4		Total Atkinson friction factor of buntons
KIC	-			Key Industry Consumer
k_{Shaft}	kg/m^3	Ns^2/m^4		Atkinson friction factor for shaft
k_{Total}	kg/m^3	Ns^2/m^4		Atkinson friction factor for total shaft
ktpm	tonnes			Thousands of Kilotonnes per month
L_{B1}	m	ft		Length of the primary bunton support
L_{B2}	m	ft		Length of the secondary bunton support
L_{B3}	m	ft		Length of the tertiary bunton support
L_S	m	ft		Length of shaft
P	Pa	Bar (mm Hg)	in. WG	Pressure
P_{ws}	Pa			Saturated vapour pressure
P_{Bar}	Pa			Barometric pressure
P_{FS}	m	ft		Resultant perimeter of shaft (from free cross-section)
PGM	-			Platinum Group Metals
$P_{L\ (Atkinson)}$	Pa			Pressure loss calculated in accordance with Atkinson friction factor
$P_{L\ (Darcy)}$	Pa			Pressure loss calculated in accordance with Darcy-Weisbach formula using the Chezy-Darcy friction factor
$P_{L\ (meas)}$	Pa			Measured pressure loss
$P_{L\ (Rational)}$	Pa			Pressure loss calculated in accordance with rational theory
P_{SC}	Pa			Pressure loss as a result of the stationary cage

P_{MC}	Pa		Pressure loss as a result of a moving cage
$P_{MC\ (Max)}$	Pa		Maximum pressure loss of a moving cage (moving against airflow)
$P_{MC\ (Max)}$	Pa		maximum pressure loss of a moving cage (moving with airflow)
Power	W		Measurement of power
Per	m	ft	Perimeter of shaft
P_{Static}	Pa		Static pressure
P_{Tot}	Pa		Total pressure
P_w	Pa		Vapour pressure
Q_F	m^3/s		Volumetric flow rate
R	J/(kgK)		Rydberg constant
r	kg_{water}/kg_{air}	g/lb	Moisture content
r_0	kg_{water}/kg_{air}		Moisture content of saturated air at t_{wb}
SD	m	ft	Shaft diameter
SD_{FS}	m	ft	Resultant diameter of shaft (from free cross-section)
T	°C	°F	Temperature
T_{DB}	°C	°F	Dry bulb temperature
T_{WB}	°C	°F	Wet bulb temperature
U	m/s	Fpm	Velocity of air in the shaft
V	m/s		Velocity
V_{FS}	m/s		Ventilation air flow in free area of shaft
V_P	Pa		Velocity pressure

VRT	°C			Virgin rock temperature
V_{Conv}	m/s			Velocity of moving conveyance
W	m			Width
w_1	m	inches		Average width of the main buntons
w_{b2}	m	inches		Average width of the secondary buntons
w_{b3}	m	inches		Average width of the tertiary buntons
w_{bf}	m	inches		Average width of all buntons (from total frontal area)
WWB	-			West Wits Basin
ΔP	Pa			Pressure difference
$\Delta P/m$				Pressure difference per metre of shaft length
ε	m			Roughness (shaft wall)
λ	-			Frictional resistance in shaft
ν	m^2/s			Kinematic viscosity
ρ	kg/m^3	lb/ ft^3	$slugs/ft^3$	Density
Γ_{B1}				Rational resistance of bunton set 1
Γ_{B2}				Rational resistance of bunton set 2
Γ_{B3}				Rational resistance of bunton set 3
Γ_{BTotal}				Overall rational resistance of buntons
Γ_{Shaft}				Rational resistance of shaft
Γ_{Conv}				Rational resistance of conveyance
Γ_{Total}				Calculated total rational resistance