University of Southern Queensland

Faculty of Engineering and Surveying

Pump Gland Improvement Project

A dissertation submitted by

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ABSTRACT

The need for this research project has arisen principally due to the economic cost incurred from poor reliability of a pump group within the Rio Tinto Alcan Gove Alumina refinery. This poor reliability issue concerns the glands on a pump group whose reliable operation is critical to the success of the business. This research project has identified the root cause of the problem and in turn provided a solution.

The Alumina industry relies heavily on slurry pumps to transport liquids and solids throughout the refining process. The failure of these pumps can significantly impact on a refineries ability to produce and consequently the reliability of the equipment is a major focus. Slurry pumps often utilise tradition stuffing box style glands to seal the wet end of the pump from the atmospheric and are usually the first part of a pump to fail. At the Rio Tinto Alcan Gove alumina refinery the mill injection pump group have been experiencing repetitive gland failures which have been costing the operation approx $12,000 per day. It is these pumps that the project has concentrated on.

The critical objectives of this research project include

- Identification of the reliability project
- Identification of the root cause
- Proposal of a solution to mitigate the effect of the root cause.
- Implementation of the solution.

To achieve these objectives several methodologies have been employed.

- Comprehensive review of production and maintenance cost associated with these pumps.
- Literary review to examine past works involving pump gland on site and globally.
- Detailed failure investigation.
- Conducting of an Apollo root cause analysis to identify the root cause and provide the best solution to mitigate it.
- Implementation and validation of the solution.

With all objectives achieved the completed project has obtained it desired results. Since the solution has been implemented there has been a significant reduction in gland failures with no recorded production losses. The time and capital expedited on this project has returned many times its value.

ACKNOWLEDGEMENTS

Appreciation is given to the following groups for information and materials used in this project.

Rio Tinto Alcan Gove (RTAG)

Weir Warman Pumps

KSB Pumps Australia

Chesterton Mechanical Seals

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NOMENCLATURE

Reliability- the probability that a device will perform its intended function during a specified period of time under stated conditions.

Utilisation - Utilisation is a measure of the time that the plant is utilized, albeit productively or non-productively. (Operating Time / Calendar Time)

Availability - Availability is a measure of the time that plant and equipment is available to perform its intended function over a defined period. (Available Time / Calendar Time)

MTBF - is used to quantify the reliability in operation of equipment. (Utilised Time / Number of Failures)

SFL – Strong Feed Liquor

Scat – A worn segment of Mill Rod or Ball.

NPSHr – Net positive suction head requirements for a specific pump to run with adequate suction pressure and avoid cavitations.

BEP – The best efficiency point (BEP) is the flow rate where a pump has its highest efficiency.

Head – Liquid force measured by elevation.

P.P.E – Personnel Protection Equipment

EHS – Environment, Health and Safety

MST – Maintenance Scheduled Task

NPV - Net Present Value

CHAPTER 1
INTRODUCTION

1.1 Outline of the Study

The need for this research project has arisen principally due to the economic cost incurred from poor reliability of a pump group within the Rio Tinto Alcan Gove Alumina refinery. This poor reliability issue concerns the glands on a pump group whose reliable operation is critical to the success of the business. Previous projects which have been carried out with the aim of improving the gland reliability have had little success. Additionally there is often frequent discussion within the Alumina industry concerning pump gland reliability and the lack of resources that specifically target slurry pumps glands as opposed to “clean fluid” pumps. The intention and scope of this project is laid out in 1.4 Research Objectives.

1.2 Introduction

Whilst the field of Reliability engineering is not new there has been a relatively recent escalation on its importance which has been born out of the need for industry to maximise their return on their investment in their equipment. Equipment failure can impact a business in many ways such as production loss cost, maintenance costs and environment, health and safety and therefore the solution to preventing these failures can yield valuable proceeds. To find the optimum solution the root cause will need to be understood.

1.3 The Problem

The Alumina industry relies heavily on slurry pumps to transport liquids and solids throughout the refining process. The failure of these pumps can significantly impact on a refineries ability to produce and consequently the reliability of the equipment is a major focus. Slurry pumps often utilise tradition stuffing box style glands to seal the wet end of the pump from the atmospheric. Pump glands often are usually the first part of a pump to fail and often are merely symptom of a bigger issue within the pump or the process of which the pump is subjected. This research project will examine a gland failure issue and attempt to produce a solution which will in turn positively impact the reliability of the pump group.

1.4 Research Objectives

The critical objective of this research project is to identify a reliability project, isolate the root cause and propose a solution to mitigate the effect of the root cause.

The format of this project will be closely aligned with the project specification (Appendix A). To ensure that the project meets all poignant completion dates a plan has been step up so as to track the progress (Table 1.1).

1.5 Conclusions: Chapter 1

The results of this study is expected to demonstrate a problem solving methodology which enables the reliability engineer to solve a problem with an unknown solution.

The background and literature review will consist of a review of Slurry pumps, principally focusing on the gland composition, failure modes and performance and provide background in the equipment reliability issue which the project is involved. This will assist in the identification of the root cause and also a solution to the problem.

	Active
	Due
	Inactive

Time Line for completion of Research Project milestones (Mill injection gland reliability project)

Start of Week	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17
	28-Feb	7-Mar	14-Mar	21-Mar	28-Mar	4-Apr	11-Apr	18-Apr	25-Apr	2-May	9-May	16-May	23-May	30-May	6-Jun	13-Jun	20-Jun
Project Proposal Submission																	
Read Project Reference Book																	
Project Specification Submission				Due													
Develop timeline to Complete Project																	
Build Document Shell																	
Research slurry pump sealing in industry (preferably the Alumina industry) with respect to designs, performance and reliability.																	
Investigate previous improvement projects which have been previously performed on this pump group																	
Collect and analysis the data concerning the “cost to the business” that have resulted in the mill injection pumps poor gland performance.																	
Develop an evaluation plan for the collection and monitoring of historical and current data concerning the gland performance on the mill injection pumps.																	
Project Appreciation Submission													Due				
Analysis the field data for the purpose of isolating the root cause or causes.																	
Commence developing potential solutions																	

Start of Week	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17
	19-Jul	26-Jul	2-Aug	9-Aug	16-Aug	23-Aug	30-Aug	6-Sep	13-Sep	20-Sep	27-Sep	4-Oct	11-Oct	18-Oct	25-Oct	1-Nov	8-Nov
Read Project Reference Book																	
Develop timeline to Complete Project																	
Perform Root cause Analysis (Write up report)																	
Submitt Extended Abstract and Work Experience					Due												
Complete Mathamatical analysis to validate solution (Write up report)																	
Obtain costing reports to impliment solution (Write up report)																	
Present solution to management (Write up report)																	
Impliment solution (Write up report)																	
Validate solution (Write up report)																	
Draft Submission Submitted									Due								
Submitt Complete Project															Due		

(Table 1.1)

CHAPTER 2

SAFETY REVIEW

2.1 Safety Introduction

An Alumina refinery is an inherently a dangerous place, the caustic which is used to dissolve the alumina also reacts with human tissue essentially dissolving it. The product is pumped at temperatures of over 200ºc and pressures of over 4000kPa. This makes any incident where the exiting of the product from the system into the atmosphere potentially a dangerous one. The process that is required to be followed in order to manage these risks in the refinery which is found in the EHS procedural manual is essentially simplified as

- Identifying the Hazard
- Identifying the Risk
- Placing controls to manage the risk

The Likelihood / Consequence matrix (Table 2.1) is a widely used tool which enables risk to be categorised with the intent of determining the level of control required.

Likelihood	**Consequence**				
	1 - Minor	2 - Medium	3 - Serious	4 - Major	5 - Catastrophic
A - Almost Certain	**Moderate**	**High**	**Critical**	**Critical**	**Critical**
B - Likely	**Moderate**	**High**	**High**	**Critical**	**Critical**
C - Possible	**Low**	**Moderate**	**High**	**Critical**	**Critical**
D - Unlikely	**Low**	**Low**	**Moderate**	**High***	**Critical**
E - Rare	**Low**	**Low**	**Moderate**	**High***	**High***

Table 2.1. (Rio Tinto Alcan Gove procedural Manual GPM-EHS-001)

2.2 Identifying Hazards

Pump gland failures often result in the product exiting the stuffing box region of the pump under high pressure. This presents a hazard particularly when the product is caustic slurry at 105 ºc. In the event of a human to be in the vicinity of a sudden gland failure a realistic consequence would range from a minor chemical / thermal burn to a serious chemical / thermal burn which would result in a loss time injury. This identifies a hazard with a serious consequence if nothing is done to control it.

2.3 Identifying risks

To quantify the hazard so appropriate controls can be in place the Likelihood / Consequence matrix is used (Table 2.1) this compares the severity of the hazard with likelihood of it occurring. Fortunately glands typically fail gradually therefore while the hazard is potentially serious the likelihood of it occurring would be unlikely. Therefore the risk can be classified as moderate.

2.4 Controlling the Risk

To manage a moderate risk Table 2.2 is referred to. Table 2.2 suggests that the risk can be managed through control which routine monitoring of the effectiveness of these controls and periodic review.

Residual Risk Rating	Tolerability	Action Message
Critical	Intolerable	Significant and/or urgent action is required to eliminate or reduce the risk level. Area Superintendents must allocate resources and review the risks. Consider Quantitative risk assessment.
High	Intolerable	Develop a Risk Reduction Plan to eliminate or reduce the risk to a tolerable level. Consider Hierarchy of Controls and ALARP (*as low as reasonably practicable)* principles.
Moderate or Low	Tolerable	Maintain controls, and ensure risks are periodically monitored and reviewed.

Table 2.2. (Rio Tinto Alcan Gove procedural Manual GPM-EHS-001)

In Table 2.3 the preferred selection of controls process is illustrated. This enables the most optimum and practical control to be put in place.

Hierarchy of controls		
Control Flow	**Hierarchy**	**Control Definitions**
Step 1	Eliminate	Physical risk control methods complying with legal requirements, preventing any contact with power source or the situation and which **cannot** be changed by human activity.
Step 2	Substitution	Replacing one substance or activity with a less hazardous one.
Step 3	Engineering	Physical risk control methods complying with legal requirements, preventing any contact with power source or the situation and which **can** be changed by human activity. They reduce or limit the exposure
Step 4	Administrative & Training	Approved working methods, procedures, inspection, observations, and regulations. Examples: JSEAs, clearance procedure, confined space procedure, coaching, mentoring, competency based training. .
Step 5	Protective Devices	Signage, barricading, pedestrian crossing, definition of work area, posters, PPE etc

Table 2.3. (Rio Tinto Alcan Gove procedural Manual GPM-EHS-001)

In the case of the Rio Tinto Alcan Gove refinery the following protocol is to be followed when working in and around online pumps.

- Perform relevant inductions – Visitor is aware of potential dangers and what to do if they are encounter. I.E. Safety shower location, Radio channels, ECT.
- Seek permission from operation before entering the area – This will enable communication of any hazard so the visitor is aware.
- Perform a personnel hazard assessment upon entering the area to ensure all is safe.
- Gland guards are to be in place – This will divert any product which exits the stuffing box towards the ground.
- PPE to be worn – In the case of an incident some protection will be given.
- Area to be barricaded in the event of a gland failing.

With these controls in place the risk is now understood to be managed and allow safe access for workers.

CHAPTER 3

MILL INJECTION PUMP OVERVEIW

3.1 Aims of the Chapter

The specific aims of this chapter are to:

- Provide an introduction to the Rio Tinto Gove Alumina refinery, its location, function and the Bayer process.
- Provide the justification for the reliability issue concerning this research project.
- Explain the purpose and composition of the Mill injection pump group

3.2 Introduction

3.2.1. Location

The Rio Tinto Alcan Gove Bauxite Mine Alumina Refinery is situated on the Gove Peninsular in the N.E region of Arnhem Land in the Northern Territory next to the purpose built town of Nhulunbuy.

Figure 3.1. (http://www.sailing-story.com/images/darwin-nhulunbuy-map.jpg, 17/05/2010)

3.2.2. Refinery Function

The refinery which was first commissioned in 1972 utilises locally mined bauxite to produce Alumina. The refinery is currently producing 3 million tonnes of Alumina per annum which makes it the 5th largest Alumina refinery in the world (http://en.wikipedia.org/wiki/List_of_alumina_refineries). The refinery extracts the Alumina from the Bauxite using the Bayer Process.

Figure 3.2. (http://www.riotintoalcan.com/ENG/resources/image_library_1456.asp, 17/05/2010)

3.2.3. Bayer Process

At the Gove refinery the Bayer process (See Pictured) achieves it purpose through the following process.

- Bauxite is strip mined (6.8 million tonnes annually), crushed to <25mm and loaded on a system of conveyors which deliver the ore to the refinery stockpiles 18km away.
- The Bauxite is reclaimed and delivered into the mills where the dry bauxite is blended with a Caustic solution then ground to a fine paste. It is here that the extraction of the Alumina from the bauxite begins as the caustic dissolves the alumina.
- The caustic slurry is then feed through a series of pressure vessels and heat exchangers to allow the maximum absorbsion of alumina from the bauxite.
- The slurry is then separated into two streams where the mud solids are sent out to the residue disposal and the alumina rich "liquor" is feed through filtration and into the "white side" for crystal growth.

- In the white side the liquor is allowed to cool and then passed through a series of filters so as to extract the hydrated (wet) alumina.
- The hydrate is then conveyed to calcinations where the hydrate is passed through fluid bed calciners. At +1000c the kilns remove all bonded water to produce a dry alumina ready for export.

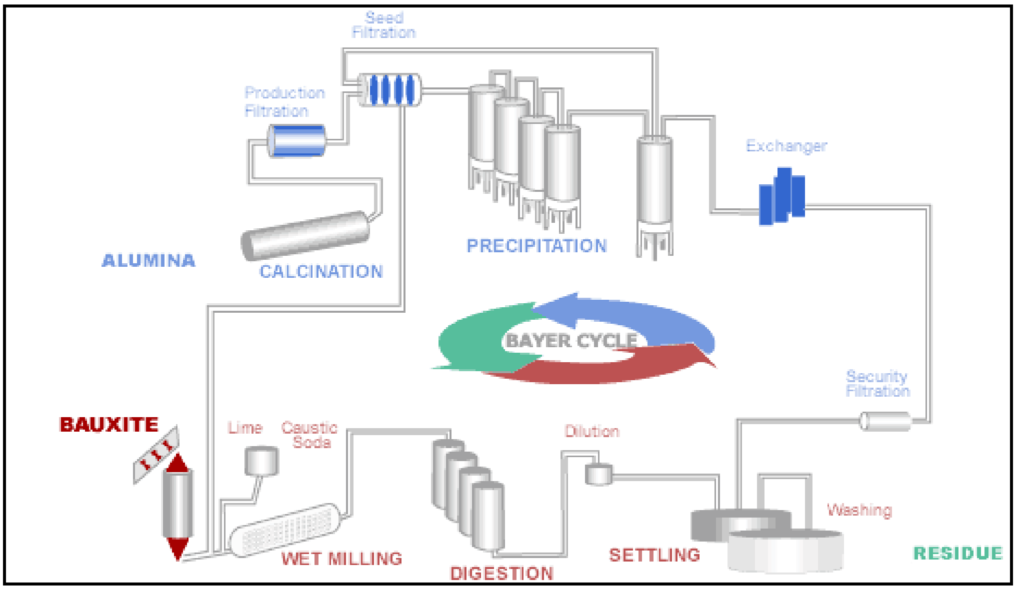


Figure 3.3. (http://www.redmud.org/images/0.C2.gif, 15/05/2010)

To perform the Bayer process the refinery relies on large volumes of caustic slurry and liquor to be transported through an extensive and complex piping system. To achieve this, the refinery has dedicated approximately 400 of its approximate 1000 pumps to pump product in various forms throughout its piping network.

Due to the dependence of the process on slurry pump performance poor performance can have a significant impact on the output of the refinery. When an event occurs though poor performance it is measured as a production loss.

3.3 Identification of a Reliability Project

Production targets for the refinery are forecast on a daily basis. When the refinery fails to achieve the targeted tonnage rates the events which led to the short comings are tabled and published as the daily production loss reports. These reports identify the production loss event. Table 3.1 displays an exert of an event from the Production Loss report.

Start	End	Event	Area	Category	Equipment	Root Cause	Event Category	Actual Variation
1-Apr-10	1-Apr-10	100401 Dig 2 - Injection Group P633-4B Gland Failure	633-Mills/MSH	Mech-Breakdown	P633-4B	Construction Quality Control	Failure - Gland	-416

Table 3.1 Exert from Production Loss report

These losses are reviewed weekly by the Reliability engineering team which uses the data to highlight the areas where the equipment reliability is performing poorly. Projects are then developed using this data. Pumps which make up the lions share of the rotating equipment on site can and often do feature heavily in the production reports and hence numerous projects concerning pumps are developed for the Pump reliability engineer to work on.

One pump group in particular has continued to dominate the production loss reports and on reference to Chart 3.1 it is evident that the mill injection group has been the number one contributor to production losses for pumps in the time period measured. These losses total 34,500 tonnes which equates to $10,350,000 @ $300 per tonne of alumina (2010-04-16 spot price of Alumina from LME) or $12,621 per day.

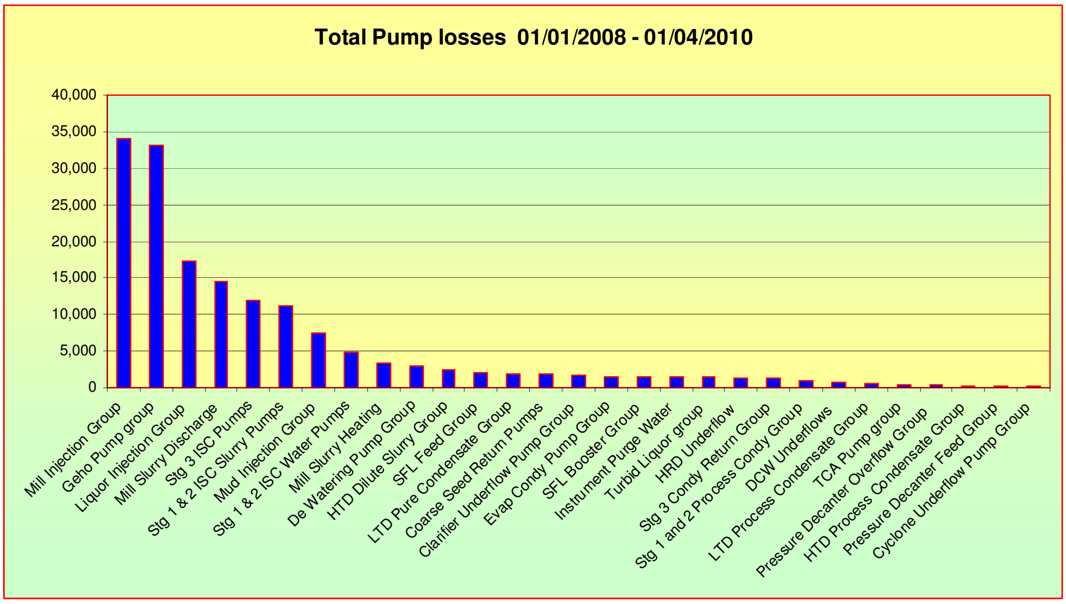


Chart 3.1 Pump Losses for all groups

High production losses are not the only indicator of high cost equipment in the refinery. Further examination of the process loss reports reveals that the of the 34,500 tonnes of alumina losses attributed to the Mill injection group 99.3% of them relate to Gland failures and 0.7% are attributed to Drive belt failures.

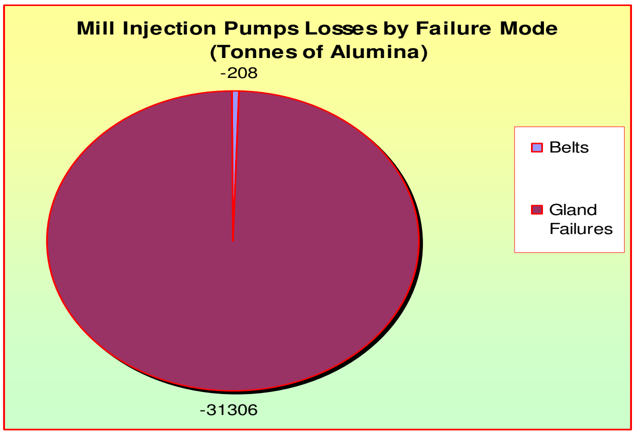


Chart 3.2

Using the MTBF calculation of (*Run Time/Failure count)* for a given time period the MTBF can be calculated for similar pump groups across the refinery.

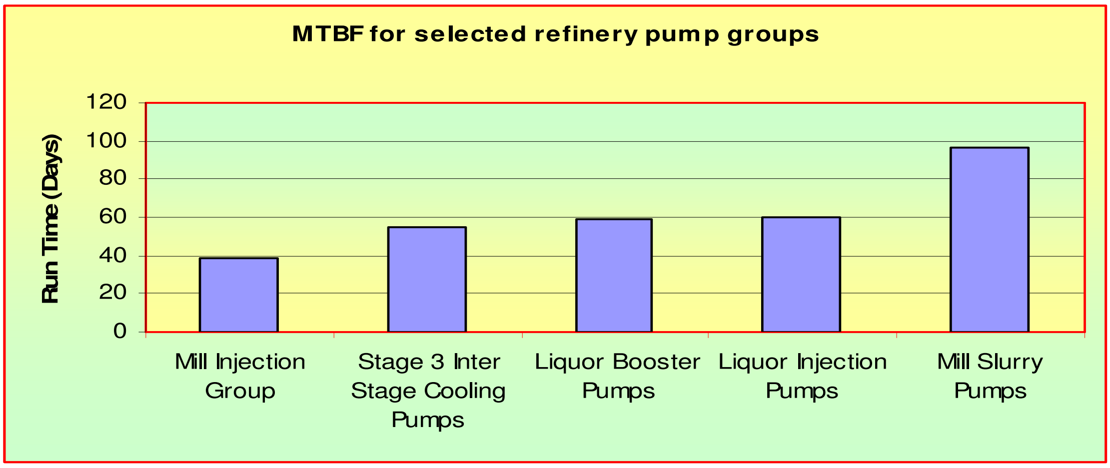


Chart 3.3

The results pictured in chart 3.3 displays the fact that the mill injection group have one of the lowest MTBF for glands on site and coupled with their high availability requirements (4 groups feeding three stages) lead to why the Mill injection group feature so heavily on the production loss reports.

This low MTBF not only cost the business in lost production tonnes but also contributed to high maintenance expenditure. An examination of the maintenance record associated with this pump group shows that from the period of 01/01/2007 there were 207 gland repack events carried out (see Chart 3.4). At an average labour rate of $100.00/hr and using an average of $600.00 worth of materials the total maintenance cost to perform a 4 hour repack for each gland failure event is $207,000 or $2000 on a weekly basis.

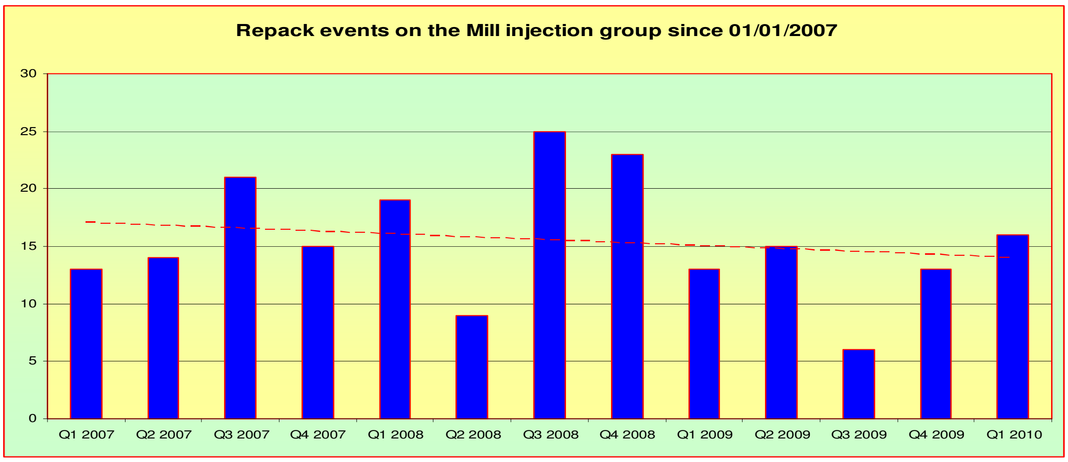


Chart 3.4

Another important fact to be gleaned from the chart is the fact that the occurrence of gland failures has remained fairly stable over the last several years this indicates that there has been no real improvement in MTBF.

With the data which has been presented the following summarisation can be made.
The Mill injection Gland failures are currently costing the refinery approximately $13,000 dollars per day in production losses. (2010-04-16 spot price of Alumina from LME) and maintenance costs. The successful completion of this research project concerned with identification of the root cause and implementation of a solution would give significant return on the invested time and energy by the reliability engineer.

3.4 Mill Injection Group

Mill Injection Pumps transport caustic slurry from the Mill relay tanks to the Low temperature digesters in stage 1, 2 and 3. Due to the elevation of the digesters and the pressures associated within the vessels the discharge pressure of the pumps need to be in the vicinity of 2000 kPa. This is achieved by having two pumps in series. One pump operates as the low pressure pump and feeds slurry to the high pressure pump. For the three stages to maintain flows there are 4 individual pump groups A, B, C and D. This provides redundancy in the system in the case of a pump group requiring maintenance so as not to affect flows. In the event two pump groups experience a mechanical or electrical failure flow cuts to a stage will be experienced which will then be recorded as a production loss.

The pumps are identified using the site standard equipment identification.
A GROUP – Low pressure pump P633-4A, High pressure pump P633-5A
B GROUP - Low pressure pump P633-4B, High pressure pump P633-5B
C GROUP - Low pressure pump P633-104C, High pressure pump P633-105C
D GROUP - Low pressure pump P633-304D, High pressure pump P633-305D

- P – equipment type (Pump)
- 633- Area of refinery equipment is found
- 4 – Low pressure, 5 – High Pressure
- A - Group identifier

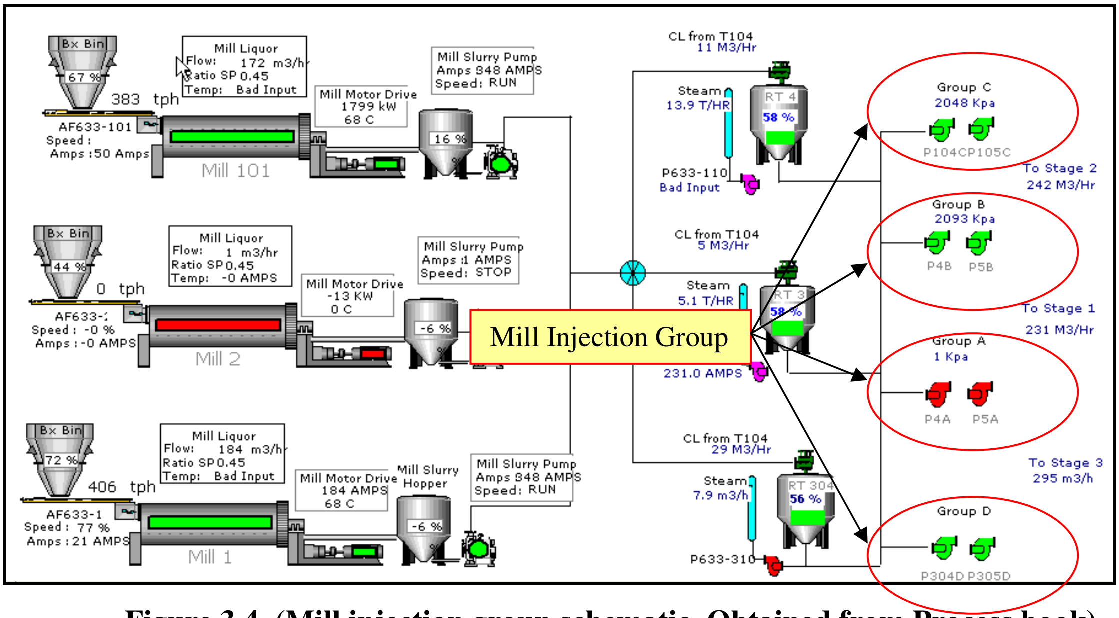


Figure 3.4. (Mill injection group schematic. Obtained from Process book)

3.4.1 Expansion of Refinery

In 2007 the refinery underwent an expansion where a third stage was built. To accommodate this the mill injection pumps was increased by another group (D).

The consequence of the expansion meant that instead of three groups feeding two stages – which required 66% utilisation it then required that 4 groups feed three stages which requires 75% utilisation. This increased the reliability requirements of the pump groups.

3.4.2 Pump Makes

A, B and C Group. Comprises of three K&L 6X8 LSA25 on the low pressure side and three K&L 6X8 LSA25 HP on the high pressure side.

K&L refers to the pump manufacturers (Kelly and Lewis), 6 x 8 refers to the discharge and suction pipe size respectively (inches), LSA refers to slurry application , 25 refers to the impeller diameter size (25 inches) and HP refers to high pressure application.

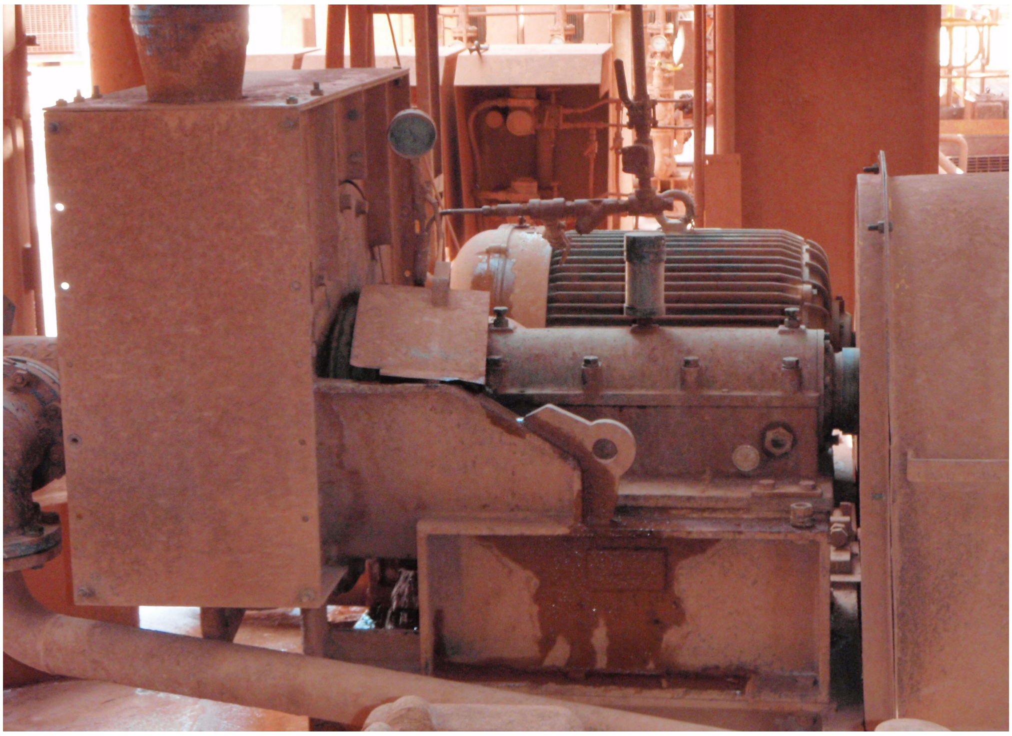


Figure 3.5. Mill Injection Pumps **(note the steel shroud over the pump which acts as a safety guard in the event of a scat from the mill enters the pumps and causes catastrophic failure)**

These pumps have been in service since 1972 (Plant commissioning) and are generally subjected to the following conditions

- Maximum Flow – 366m3/hr
- Normal Flow – 340m3/hr
- Minimum Flow – 206m3/h
- Slurry SG – 1.824 / Solids SG – 2.4 / Liquid Density – 1.3 / Concentration – 54.8%

On the low pressure side the pumps are driven by a fixed speed 160kw AC motor the power is transferred through a reduction belt drive and delivered to the pump at 811rpm. The high pressure pumps are similar except for the fact that a variable speed fluid drive is utilised between the motor and the v-belt pulley this enables the High pressure pump to regulate its discharge pressure.

D Group. Comprises of a Warman 6x8EE - AH on the low pressure side and a Warman 6x8FF-AHP on the high pressure side. Warman refers to the manufacturer (Weir Minerals), 6 x 8 refers to the discharge and suction pipe size respectively (inches), EE or FF refers to the frame size (Bearing cartridge) respectively and AH indicates that is for an abrasive heavy duty slurry application and the P indicates high pressure.

These pumps have been in service since 2007 (3^{rd} stage commissioning) and are generally subjected to the following conditions (same as A, B and C group)

- Maximum Flow – 366m3/hr
- Normal Flow – 340m3/hr
- Minimum Flow – 206m3/h
- Slurry SG – 1.824 / Solids SG – 2.4 / Liquid Density – 1.3 / Concentration – 54.8%

On the low pressure side the pump is driven by a fixed speed 185 kW AC motor, power is transferred through a reduction belt drive and delivered to the pump at 1028rpm.The high pressure pump is identical except for the fact that the motor is controlled by a VSD. This way the speed as with the A, B and C group the speed can be regulated to control pressure to the digesters.

Figure 3.6. D Group Pumps

This pump group forms a critical part of the refinery. The unplanned failure of these pumps immediately limits the ability of the refinery to make alumina which then leads to loss of income.

CHAPTER 4
LITERATURE and BACKGROUND REVEIW

4.1 Aims of the Chapter

The specific aims of this chapter are to:

- Research the basic features of a centrifugal pump.
- Describe the unique features of Slurry Pumps
- Provide a description of pump glands their composition and purpose.
- Research failure modes concerning pump glands
- Outline current industry methods in improving slurry pump gland reliability
- Indentify previous work or reliability projects which have been carried out on the mill injection pump glands.
- Provide an evaluation of the information researched.

4.2 Introduction to Centrifugal Pumps

Pumps are used to transfer liquids from low-pressure zones to high-pressure zones (Bachus, 2003, p.1). To do this effectively the liquid needs to be at the suction of the pump at a required pressure so the pump can work with the fluids attributes. Centrifugal pumps cannot draw fluid into the housing.

$$P_1/\gamma + v_1^2/2g + Z_1 = P_2/\gamma + v_2^2/2g + Z_2 = P_3/\gamma + v_3^2/2g + Z_3$$

Bernoulli's Equation

The principal components in a pump which gives it the ability to transfer liquids is the volute and the impeller. The impeller rotates on a shaft and allow liquid to enter its eye (See Figure 4.1). The liquid then travels along the impeller vanes and is accelerated towards the outside of the impeller. Following Bernoulli's equation this creates a low pressure zone at the eye of the impeller due to the increase in velocity. When the fluid reaches the end of the impeller the velocity rapidly decreases which increases the pressure. Due to the positioning of the impeller and the shape of the volute the fluid is then forced along a path by the impeller and direct towards the discharge. As the fluid travels around the volute the velocity decreases due to the increasing area available for it to fill the effect of this is an increase in fluid pressure.

This pressure differential that has developed between the suction and the discharge now allows the liquid to be transported through a piping system at a specific flow rate with a specific head.

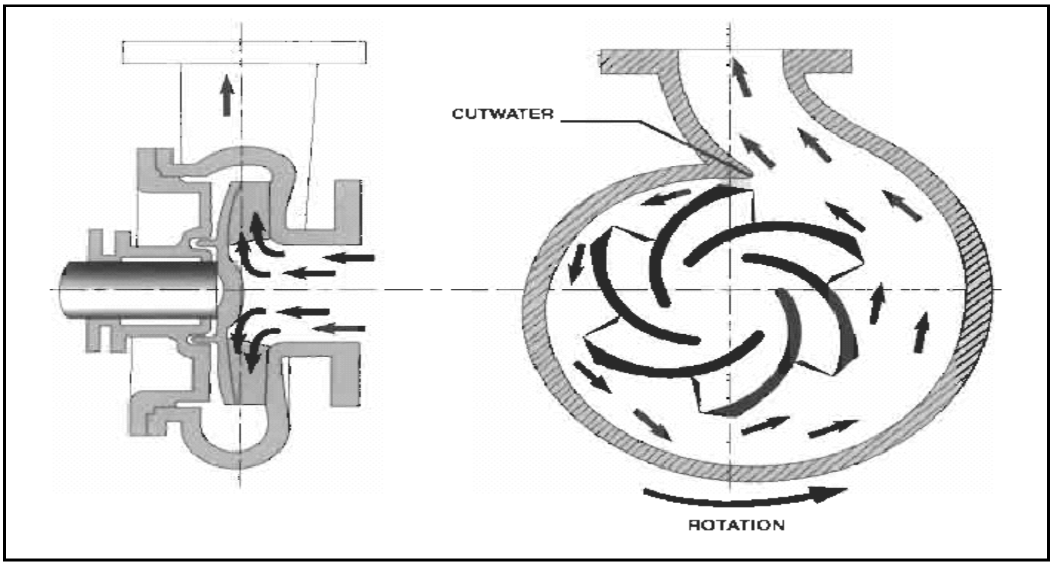


Figure 4.1 Pump Dynamics (Bachus, 2003, p.3)

On the manufacture of a pump impeller, designers will subject the impeller to hydraulic testing, this testing involves the flows produced by the impeller gradually being restricted until flow shut off is achieved. The data which includes flow rates, power consumption, discharge and suction heads is collected and presented on what is known as a flow curve (see Figure 4.2), Each impeller design has its own flow curve and enables engineers to design a pumping system to match the flow and pressure requirements. In the interest of efficiency it is always preferable to run the pump as close to the best efficiency point as possible. The B.E.P is the point where the power coming out of the pump (water horse power) is the closest to the power coming into the pump (brake horse power) from the driver. This is also the point where there is no radial deflection of the shaft cause by unequal hydraulic forces acting on the impeller. (http://www.mcnallyinstitute.com/Charts/Glossary-html/Glossary_B.html 18/05/2010)

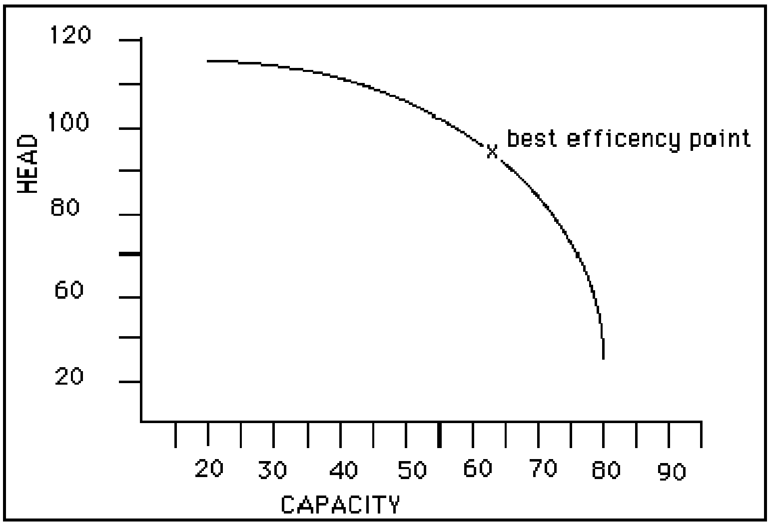


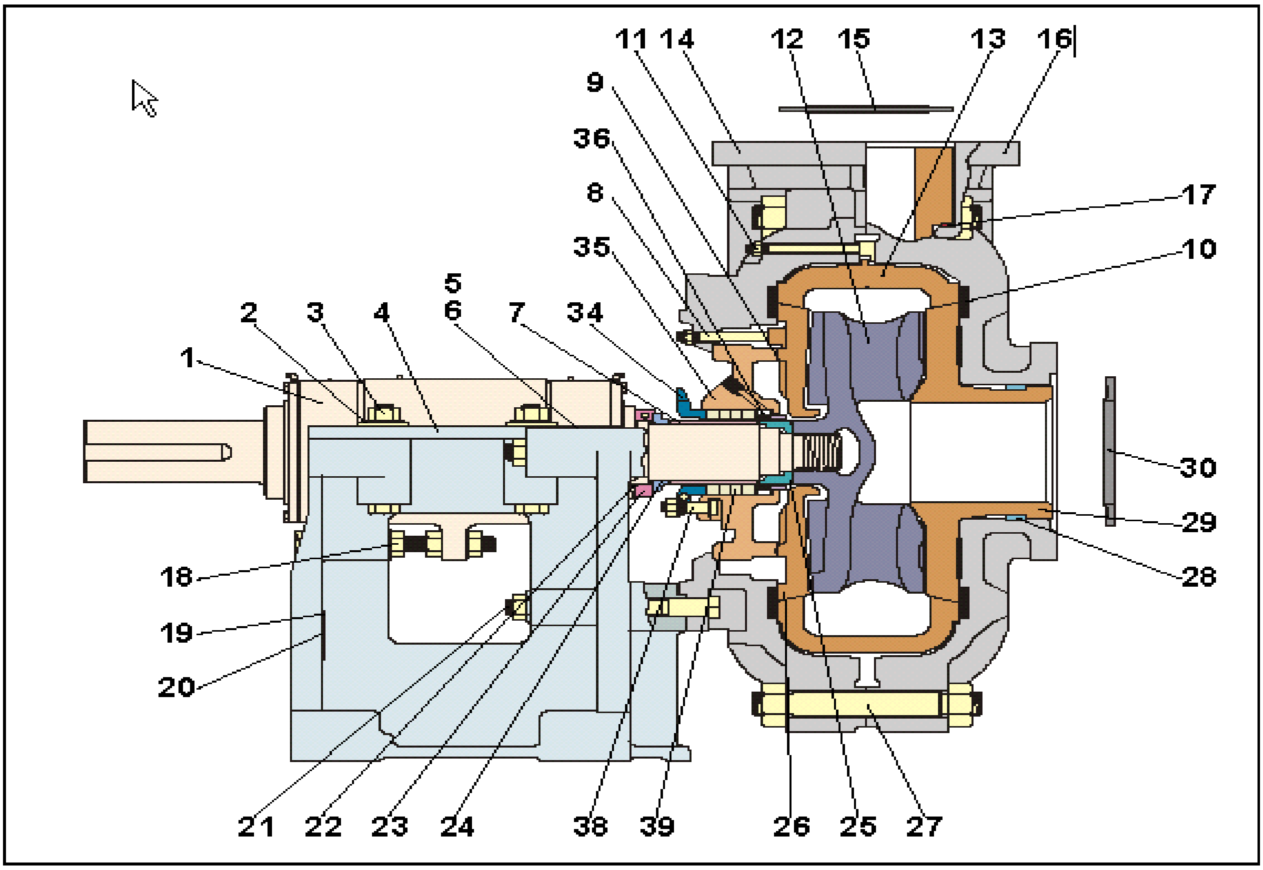
Figure 4.2 Flow Curve (McNally Institute 2-3)

4.3 Introduction to Slurry Pumps

Slurry pumps are used to transport solids in a liquid medium. The solids may consist of bauxite, silica and other minerals which can be up to10mm in diameter and are highly abrasive. This aggressive application challenges traditional “clean fluid” pump technologies and has forced pump manufacturers to incorporate numerous design changes into their components to perform the duty as per requirements. The changes include the following.

- Usage of high chromium alloys “white iron” to resist abrasive wear in the wet end components.
- Greater wall thickness’s in the wear components.
- Greater internal clearances concerning the impeller to throat bush (reduced Efficiency)
- Greater use of packing as opposed to mechanical seals for pump sealing.
- Different pump stuffing box configurations as opposed to clean homogenous solution pumps.
- Greater shaft rigidity.
- Larger bearing sizes to accommodate bigger loads.
- Blunt tipped impellers.
- Lower number of vanes used in the impeller.
- Pump run at a lower speeds

(Slurry Pump Handbook. 2009)



P633-305D PUMPSET MILL SLURRY INJECTION .8/6FF WARMAN
8/6FF-AHP HIGH PRESSURE SLURRY PUMP, MODIFIED BASIC BEARING ASSEMBLY, GLAND SEAL, METAL LINER
Pump Parts List

ITEM	STOCK CODE	DESCRIPTION	PART NO.	QTY.	PAGE
1	000459396	FFAM005M BEARING ASSEMBLY	FFAM005M		2
2		CLAMP WASHER	F011E63	4	
3	000811588	CLAMP BOLT	F012ME62	4	
4		BASE	F003MD21	1	
5		N/P BURSTING WARNING	SD73C22	1	
6		N/P LIFTING WARNING	SD80C22	1	
7	000696260	SHAFT SLEEVE, C21A36	F076J31	1	
8		STUD, M16 x 145 O/A=161LG	M16Z3-145Z	4	
9	000696351	O-RING, 53T380N384	FP122S10	1	
10	000115329	VOLUTE COVER LINER SEAL	F8124S01	2	
11	000696559	VOLUTE LINER BOLT	FP6256E62	2	
12	000555318	IMPELLER 4VC	F6145HE2A12	1	
13	000733774	VOLUTE LINER	FP6110A12	1	
14		FRAME PLATE	FP6032D21	1	
15	000696377	DISCHARGE JOINT RING	FP6132R33	1	
16		COVER PLATE	FP6013D21	1	
17	000696385	VOLUTE LINER SEAT RING	FP6257U02	1	
18		ADJUSTING SCREW	F001ME62	1	
19		NAMEPLATE RIVET	TLP/D424BS		
20		N/P WARMAN PUMP, GRS LUBE	C6C22	1	
21		FRAME PLATE STUD	F039ME63	3	
22	000696245	O-RING, 69T126N429	S109S10	1	
23		RELEASE COLLAR, 3 PIECE, C/W TAG LBL104	S239MC21	1	
24	000696567	SHAFT SLEEVE SPACER	S179-2C21	1	
25	000017863	O-RING, 35T111N245	F109S10	2	
26	000115832	FRAME PLATE LINER INSERT	F6041MA12	1	
27		COVER PLATE BOLT, E23/MB	FP6015ME48	16	
28		COTTER	FP6085E62	2	
29	000658096	THROATBUSH	F6083A61	1	
30	000696393	INTAKE JOINT RING	GH6060S01	1	
34	000696294	GLAND, 2 PIECE, C/W GLAND CLAMP BOLTS	FP044C23	1	
35	000696203	STUFFING BOX	FP078D21	1	
36	000696286	LANTERN RESTRICTOR	F118C23	1	
38	000695411	GLAND BOLT	F045MC23	4	
39	000666495	PACKING SET, CUSTOMER SPECIFIC	TBMN05005F-SET	1	
		PARTS USED TO CONSTRUCT THE PUMPSET NOT FOUND ON ILLUSTRATIONS			3

Figure 4.3 (Obtained from a Warman parts guide for an 8/6 FF-AHP High Pressure Slurry Pump.)

4.4 Gland Configuration and Performance in Slurry Pumps

The stuffing box houses the packing assembly and is located where the shaft penetrates the casing that is under pressure. In slurry pump applications the stuffing box is bolted to the casing. The stuffing box bore is concentric to the shaft sleeve and of a specific size so as to accommodate rings of packing (Volk. 2005, p334).

Compression packing is most commonly used on rotating equipment. The seal is formed by the packing being squeezed between the inboard end of the stuffing box and the gland. A static seal is formed at the ends of the packing rings and the inside diameter of the stuffing box. The dynamic seal is formed between the packing and the shaft sleeve. (Karassik et al. 1986, p2.114). Seal water should be available at 10 psi (0.7 bar) above maximum pump discharge pressure. (LSAS Technical Booklet).

A negative attribute associated with this type of sealing is the fact that it allows considerable water into the wet end of the pump which dilutes the product. In the Alumina industry water ingress into the slurry reduces the yield and means that the water will have to later be extracted through either the evaporation or calcination process. Therefore it is important to run the gland water to an optimum level.

There are essentially two different stuffing box configurations that can be utilised by slurry pumps (See Figure 4.4).

- Low flow version is the most common in the alumina industry as it requires the least gland flush to work effectively.
- Forward flush configuration tends to be used more in high pressure pump applications (+2000kPa) due to a tendency for the packing to be extruded through the clearance of the shaft sleeve and stuffing box by the high pressure gland water which is turn on before the pump is started and pressurised. In this case water forms a barrier between the slurry and packing.

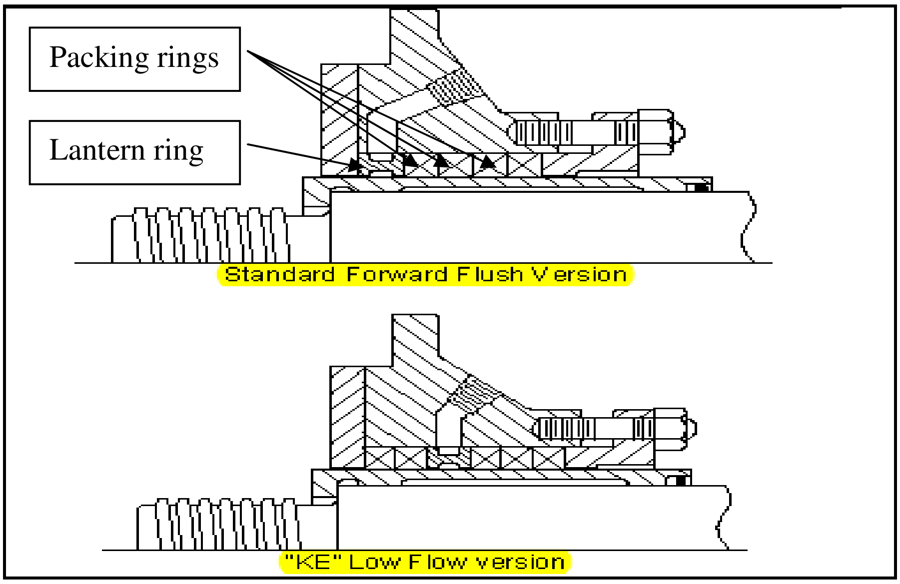


Figure 4.4 Stuffing Box Configurations (Obtained by LSA Technical Book from GIW)

These two configurations are the most common method of sealing slurry pumps, mechanical sealing is used widely however unless conditions are stable and the pump is allowed to run close to its design, problems often arise and expensive repairs can occur. Stuffing box type sealing provides a more robust configuration and is able to operate effectively under a broader range of conditions.

4.5 Gland Failure Characteristics

The following points discuss common modes of failures for pump glands. The research into this will enable a better understanding and assist when identifying the root cause of failure concerning the mill injection pumps.

4.5.1 Worn Shaft Sleeve

- Stuffing box shaft sleeves are surrounded in the stuffing box by packing: the sleeve must be smooth so that it can turn without generating heat (Karassik et al. 1986, p2.117).
- For packing to operate properly, the finish on the shaft sleeve must be at least 0.4µ m). The sleeve must be harder than the packing and chemically resistant to the liquid being sealed. (Karassik et al. 1986, p2.117).

- For pumps subject to slurry the surface must be hard so as to resist wear, chromium, tungsten carbide and ceramic and some of the materials used for severe service. If the sleeve has a coated material for a hard wearing surface, the sleeve must also have good thermal shock. (Karassik et al. 1986, p2.116).

Research into shaft sleeves suggests that the material of construction is critical to its ability to resist wear. In the case of the Gove alumina refinery the type of pump which is used in the mill injection area is also used many other applications some being considerably less severe in application than the mill injection pumps. The same shaft sleeve material is in installed into everyone of the pumps. This material while being suitable for most of the applications may not be suitable in the mill injection area.

4.5.2 Poor Packing Material Selection.

Packing requires a number of attributes to work effectively. The correct balance of these attributes is required for the optimum reliability to be achieved, the attribute are as follows

- Conformability – The ability for the packing material to adapt to its volumetric constraints and provide an effective seal.
- Lubricity – The packing is impregnated with lubricant (usually graphite) it needs to be able to retain it so as or start up it won't over heat.
- Low coefficient of expansion – As the pump shaft speed increases so does the temperature. The packing needs to expand as little as possible.
- Braid construction – Different weaving configuration can affect the packings ability to retain its shape during operation.
- Low abrasiveness – Material needs to be soft enough so as not to wear the shaft sleeve
- Ease of installation – The easier the packing is to install the less likely failure will be result

(http://www.impomag.com/scripts/ShowPR.asp?RID=7811&CommonCount=0, Al Guizzetti, Product Specialist, W. L. Gore & Associates, Inc., Newark, DE, 17/05/2010)

Having many attributes selecting the correct packing is about finding the right balance of qualities to suit the application. At the Gove alumina refinery there are two pump packing types used. This packing material has been deemed suitable to work in a wide range of applications from acid service, clean fluid and slurry. The definition of suitable needs to be investigated

4.5.3 Incorrect Gland Water Supply

- Under pressure – Slurry will force its way underneath the packing quickly abrading the packing undermining its ability to form a seal.
- Over pressure – Gland water will extrude the packing through the clearance between the shaft sleeve and the stuffing box into the wet end of the pump.
- Low flows – An important function of gland water is to remove heat from the stuffing box. Excessive heat build up will burn the packing.
- Poor gland water quality – Impurities in the gland water can block piping restricting the flow or impregnate the packing undermining its ability to seal.
- The quality, quantity and pressure of this gland sealing water is of prime importance and must be carefully matched to the duty required.
  (Slurry Pump Handbook. 2009, P2-12).

In large refineries where there are extensive gland water systems uniform pressure and flow are difficult to achieve. Further to this as the refinery ages the piping deteriorates and scaling from corrosion will progressively get worse. Pressure, flow and water quality will need to be measured at the individual pumps to ascertain whether it is a contributing factor to poor gland reliability.

4.5.4 Incorrect packing installation

- Wrong sized packing length – Excessive stuffing box clearances allows slurry to exit wet end of pump.
- Over compressed packing – Prevents gland water from cooling shaft sleeve.
- Under compressed packing – Excessive stuffing box clearances allows slurry to exit wet end of pump and into atmosphere.

This type of failure can be attributed to the training and skills of the pump tradesmen. The Gove refinery employees approximately 100 fitters with varying degrees of skills. For a chronic issue such as the mill injection glands as opposed to a sporadic one it is unlikely that poor installation is responsible.

4.5.5 Wrong Pump Application

- o High pressure spikes- Can be caused due to control valves on the discharge side suddenly opening and closing. This can cause the discharge pressure of the pump to momentarily to exceed the gland water pressure. This will inject slurry into the packing deteriorating packing life.

  o Pump operating off its best efficiency point – At the best efficiency point the balance between flow, pressure and pump area is in equilibrium. When the pump is operated away from the BEP the flow, pressure and area ratios become imbalanced which create radial forces. These radial forces will increase as the pump operates further away from the BEP. As the radial forces increase so to will the amount of shaft deflection which is occurring. The deflection will cyclically deform the packing decreasing its ability to perform its sealing duty.

  (Know and Understand Centrifugal Pumps Larry Bachus and Angel Custodio 2003)

This suggests that a pump which operated at or close to its BEP will run reliably. To do this the pump and piping system needs to ensure the following.

- Discharge valves remain in a constant position.
- There is no pipe scaling to build restriction in the lines.
- Operations require constant flows.

In reality this is not possible so some shaft deflection will be experienced and it needs to be distinguished as to what is the acceptable level of shaft deflection.

4.5.6 Mechanical Fault

- o Bearing failure – Bearing wear will increase the radial run-out of the shaft. This run-out will deform the packing decreasing its ability to perform its sealing duty.
- o Bent Shaft – Like a bearing failure and shaft deflection the bent shaft will deform the packing decreasing its ability to perform its sealing duty.

These mechanical faults would be easily detectable and the symptoms of gland failure would be expected to disappear after the corrective action has been performed.

Knowing and understanding the different failure modes which can occur in a stuffing box will be an important tool when attempting to isolate a root cause in a gland failure. They will become points of reference for later in the project.

4.6 Industry Methods in Improving Slurry Pump Gland Reliability

Slurry pumps are widely used in the resource industry due to their ability to transport solids in a liquid medium. Australia being a major producer of raw materials relies heavily on slurry pumps and consequently there is a large industry centred on the supply of products which are constantly being developed for the purpose of improving gland performance. The following products are relatively new on the market and give an example of possible solution that may be used in the mitigation of a root cause of a reliability issue concerning glands. Further information about the products can be found in Appendix B.

4.6.1. Grooved Flow Restrictor Bushes – These components are installed in forward flush stuffing box configurations and replace the standard bush installed by the pump manufacturer. The Grooved Flow Restrictor Bushes have a tapered spiral groove manufactured on the inside diameter which is counter rotational to the shaft direction. Additionally the internal diameter of the grooved section of the bush is conical, this then performs the following actions

- Gland water solids which are in suspension are separated to the outside of the bush and channelled out of the stuffing box and into the wet end.
- Pumping action of the tapered spiral increases the pressure towards the wet end maintaining an increased pressure differential.
- Reduces water usage by utilising tangential ports which distribute the water more effectively.

4.6.2. Live Loading on the Glands – For a gland to work effectively the compression on the packing needs to be maintained. Traditionally this was performed by periodic “nip ups” by the maintenance staff. However there are often factors which prohibit this action occurring and the reliability of the gland is affected. These factors include

- Poor access in the case of vertically mounted pumps or remotely located.
- Pump which present hazards such as high temperature, high pressure pumps.
- Pumps which have low maintenance intervals and experience a long time between inspections.

This product maintains a constant force on the gland follower through either spring or hydraulic loading which ensures that the compression is maintained.

4.6.3. Grease Purging of the Gland – In applications where gland water quality is poor or the pressure and flow is unsuitable grease can be used to replace the water as a flushing medium. Grease pressure is maintained through a grease pump and pumped into the gland. Due to the superior lubrication qualities of grease compared to water only a fraction of the normal flush is used.

4.6.4. Stuffing Box Bearings – Pumps that have a low shaft stiffness ratio and that are operating significantly away from their B.E.P can experience shaft deflection due to the unbalanced forces in the wet end of the pump. The Stuffing box bearing is installed in the stuffing box and provides support to the shaft close to the impeller. This minimises deflection and increases gland life by maintaining packing shape.

4.6.5. Slurry Packing- Due to the tendency for slurry pumps to be exposed to far more aggressive applications then clean "fluid pumps" slurry specific packing has been developed. Slurry packing incorporates re-enforcing fibres to maintain integrity, enhanced lubricants to reduce friction and complex braiding to maintain shape.

4.6.6. Mechanical Seals- Traditionally mechanical seals have been avoided in slurry applications. This is due to the limited range of applications a mechanical seal can be subjected to. Axial loading, shaft run out, poor flush water and high solids will all contribute to mechanical seal failure. In recent years slurry seals have been developed to better cope with these applications and consequently can be a viable solution in the case of poor gland reliability.

4.6.7. Stiffened Shaft Assemblies – These assemblies are provided by Pump manufacturers to avoid shaft deflection occurring. In the case where a pump is required to operate significantly away from its B.E.P shaft deflection can lower gland life through the deformation of the packing. The stiffened shafts or larger frames have better rigidity and are able to handle greater loading.

4.7 Previous Projects Concerning the Mill Injection Pumps

Over the last ten years there have been several projects that have investigated the poor gland reliability issue concerning these pumps. These projects were performed by engineering and maintenance personnel with the aim of mitigating the production losses. The project description and details have mostly been extracted after examining the historical records of the pump crew meeting minutes, past work orders raised and interviewing of the staff who were involved with this pump group previously. An example of this evidence of this can be found in Appendix C.

4.7.1. Gland Water Pressure Differential Project - Project was carried out in 2006 as part of a continuous improvement project. Due to process conditions the discharge pressure on the high pressure pump side fluctuates making the pressure differential between the gland water and pump discharge unstable. A pressure control system was installed to maintain a constant 200kPa difference. This ensured that the pressure differential was constant. This had a positive effect on the MTBF for the high pressure pumps (Pumps identified as having a 5 in their equipment number). Referral to Chart 4.1 displays the high pressure pumps as having a significantly higher MTBF as compared to the Low pressure pumps the exception to this is the 304D pump which is a different make of pump compared to the other three.

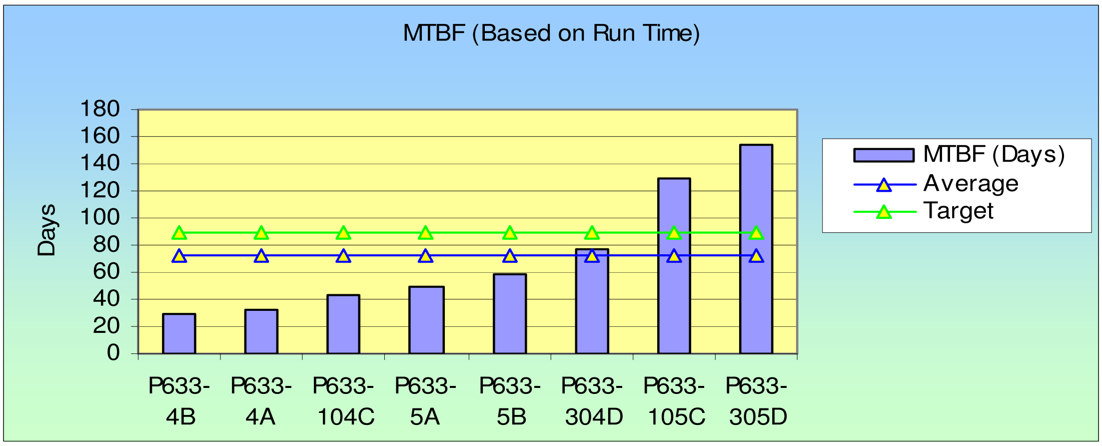


Chart 4.1

The implementation of this improvement would have little effect on the low pressure pumps as the speed and therefore discharge pressure is constant. The performance of 304D will be worth investigating as to why it performs significantly better than the other low pressure pumps.

4.7.2. Installation of a Grooved Flow Restrictor – Project was carried out in 2005 by the workshops engineer at the time. This involved the reconfiguration of the stuffing box from a standard configuration to a forward flush configuration where a grooved flow restrictor was fitted.

Project was unsuccessful and the stuffing box was re-converted back shortly after. There is no data available to analysis as to the impact the project had on the gland MTBF, however it has been suggested that the grooved flow restrictors were contacting the shaft sleeves and damaging the components.

4.7.3. Repack MST – This was instigated in 2006 by the pump maintenance co-ordinator with the aim of repacking the Pump glands on a scheduled basis before the MTBF point. A work order was raised on a fortnightly basis and the repack planned in. Using this strategy it was thought that the production loses could be avoided.

With eight pumps in the mill injection group it meant that one pump was required to be isolated ready for maintenance approximately 8% of the time. Due to process requirements operations could not afford to release the pumps for that frequency. Additionally when a pump was available pump crew often lacked the manning to perform the task. The MST was cancelled after one year.

4.7.4. Mechanical Seal Installation – Prior to 2000 there is some evidence that suggests a slurry mechanical seal was trialled on these pumps however verification has not been achieved.

Given the poor reliability associated with the pump glands it is doubtful as to the suitability of this trial.

4.7.5. Slurry Packing Trials – Throughout the operational life of the mill injection pumps there have been numerous packing trials that have been conducted. Different packing suppliers have offered to help solve the issues by trialling their products. Slurry packing with different weaves, yarn material and lubricant base have all been trialled with little effect.

Despite there being numerous slurry packing manufacturers the variation in make, quality and composition is limited. Therefore the difference in performance will also be limited. To enact a significant change in gland reliability changing the slurry packing brand is unlikely to have the desired effect. However once the root cause is addressed the fine tuning process may involve trialling different packing compositions.

4.8 Conclusions

The research conducted in this chapter has had the following purpose.

- Understand as to how pumps glands work.
- Understand how pump glands can fail.
- Understand what products or upgrades can be retrospectively installed so as to mitigate the gland failures.
- Understand the successful and unsuccessful improvement work that has already been conducted on this pump group and what effect it has had on the pump gland reliability.

The completion of this research has provided a broad understanding of the reliability issue at hand and will enable future work to be focused towards the higher probability scenarios. Using this strategy we can refer to Chart 4.1 which displays the fact that the poor gland reliability mainly exists in the Low pressure A, B and C group pumps. Therefore to maximise the value from this project we can exclude the other pumps from further analysis.

The fruits of this chapter will now lay the foundations for the following chapters which include data collection, root cause analysis and the development and implementation of potential solutions.

CHAPTER 5
DATA COLLECTION and ANALYSIS

5.1 Aims of Chapter

The specific aims of this chapter are to:

- Determine the relevant data which is to be collected based on the research conducted and existing data previously displayed in this project.
- Display data which has been collected or calculated
- Report and discuss the of relevance of the collected data

This data analysis will then be combined with the next chapter to enable a complete Root Cause analysis to be conducted.

5.2 Data Required

Referring to Chart 4.1 which displays the MTBF of the mill injection pumps. The chart indicates that the D group pumps (Warman Manufacture) and the High pressure pumps (Identified by the 5 in the equipment number) are significantly better performers than the low pressure A, B and C group pumps. This identification allows the data collection to focus on those three pumps.
The literary review in Chapter 4 indicated that the following failure modes associated with Glands are the mostly likely modes which will yield the root cause.

- Worn Shaft Sleeves
- Poor Packing Selection
- Incorrect Gland Water supply
- Wrong Pump Application
- Mechanical Fault

To confirm the relevance of each failure mode to the mill injection pumps Table 5.1 displays the information that needs to be gathered.

Data Collection Plan					
Failure Mode	**Data Requirement**	**Data Source**	**By**	**When**	**Collection Freq / Span**
Worn Shaft Sleeves	Shaft Sleeve make	Drawing Register	D.Bishop	30th Jun	Once
	Shaft Sleeve wear attributes	Visual Investigation	D.Bishop	01st Aug	2 Examples
	Shaft sleeve MTBF compared with similar.	Process History and Ellipse work orders	D.Bishop	01st Aug	Once
Poor Packing Selection	Current Packing used	Equipment Parts listings	D.Bishop	01st Aug	Once
	Packing condition after failure	Visual Investigation	D.Bishop	01st Aug	2 Examples
Incorrect Gland Water supply	Required Gland Water flow	Manufacturers Specs (LSAS Technical Booklet).	D.Bishop	01st Aug	5 Samples
	Required Gland Water pressure	Manufacturers Specs (LSAS Technical Booklet).	D.Bishop	01st Aug	5 Samples
	Actual Gland Water flow	At Pump	D.Bishop	01st Aug	Once
	Actual Gland Water pressure	At Pump	D.Bishop	01st Aug	Once
Wrong Pump Application	Flow curve of pump	Pump Manufacturer resources	D.Bishop	01st Aug	Once
	Actual flows pump is subjected to. Relation to B.E.P	Pi Historical trends	D.Bishop	01st Aug	1 Months data
	Shaft deflection experienced by the pump for given flows	Calculations using Manufacturers specifications and flow data from process history	D.Bishop	01st Aug	1 Months Data
Mechanical Fault	Mechanical inspection after gland failure	Failure Investigation	D.Bishop	01st Aug	2 Examples

Table 5.1 Data Collection Plan

5.3 Data

5.3.1 Suitability of Shaft Sleeve

Make Shaft Sleeve is manufactured from mild steel, with Metco 34F hard facing, hardness tested to Rockwell 'C' 60+.
Metco 34F is a Tungsten Carbide powder blended with nickel. The powder is thermally fused on to the shaft sleeve and requires minimal grinding. This gives the wear surface both the hardness and corrosive resistance requirements for this application.

Visual Inspections after use

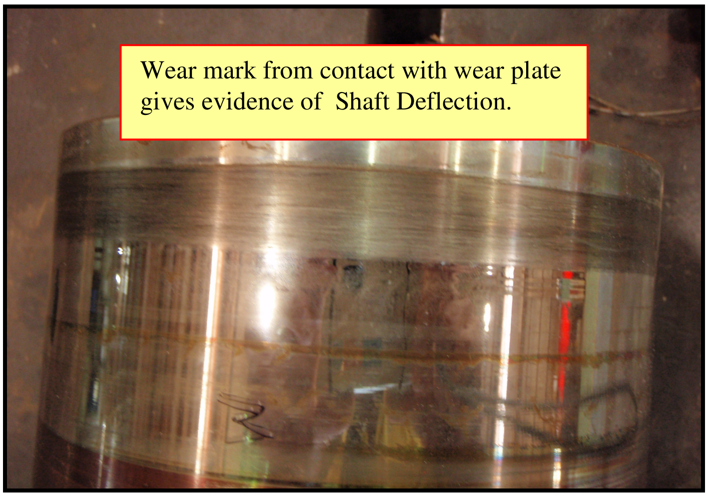


Figure 5.1 After 10 days in operation

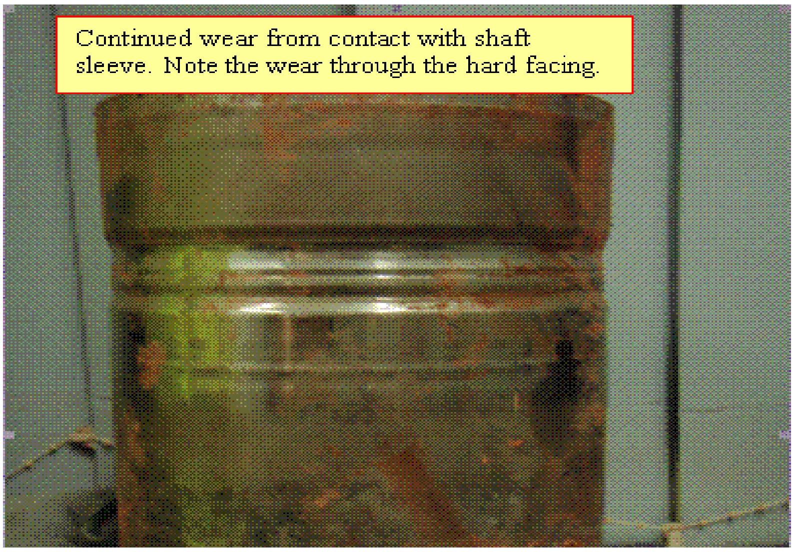


Figure 5.2 After 77 Days- rendered unusable

MTBF Current MTBF with the existing shaft sleeves is 70 days run time. This is poor compared against other shaft sleeves in similar applications where 180 days has been achieved.

5.3.2 Suitability of Packing Selection

Make Current packing used is 1400r Graphmax 3/4 sq section manufactured by Chesterton. This packing is rated to 550 deg and 120 Bar rating.

Failure Inspections

Fig 5.3 5 Days run time

Fig 5.4 21 Days run time

5.3.3 Suitability of Gland Water Supply

Required Gland Water Flow - Maximum of 18l/min Gland flush be used – No minimum stated. The document suggests that considerably lower flows than the maximum stated should be achievable with no adverse effects.

Actual Gland Water Flow – Current Maric flow restrictor set at 12 l/min

Required Gland Water Pressure - 70kPa above maximum discharge pressure.

(Obtained from LSA Technical Booklet). At 811rpm the pumps maximum discharge pressure is 49m head. With a slurry S.G of 1.824 this equates to a pressure of 868 kPa. The means that the gland water pressure of 1000 is close to the optimum recommended by the manufacturers of 940 kPa

Actual Gland Water Pressure - HP water source has been recorded at between 950 and 1000kPa depending on supply requirements.

Figure 5.6 Gland Water pressure at 950kPa

5.3.4 Suitability of Pump To Application

Flow Curve

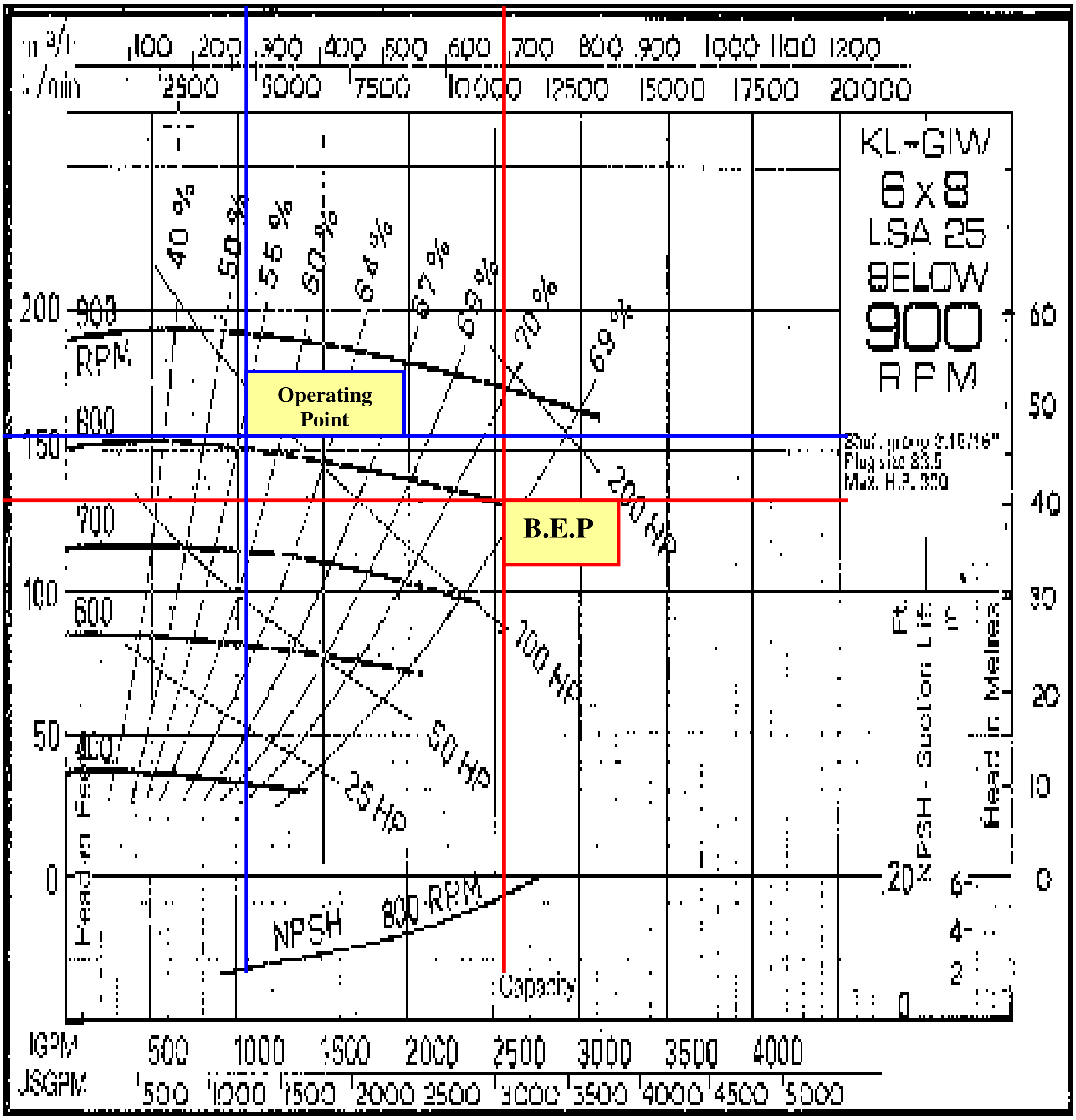


Chart 5.1 Flow Curve for 6-8 LSA -25

B.E.P for the current pump installed is at 687m³/hr and 42.9 m head (See Chart?)

Average Operating Point is 275m³/hr at 49m head.

Actual Flows pump is subjected to (Data extracted from Process history book)

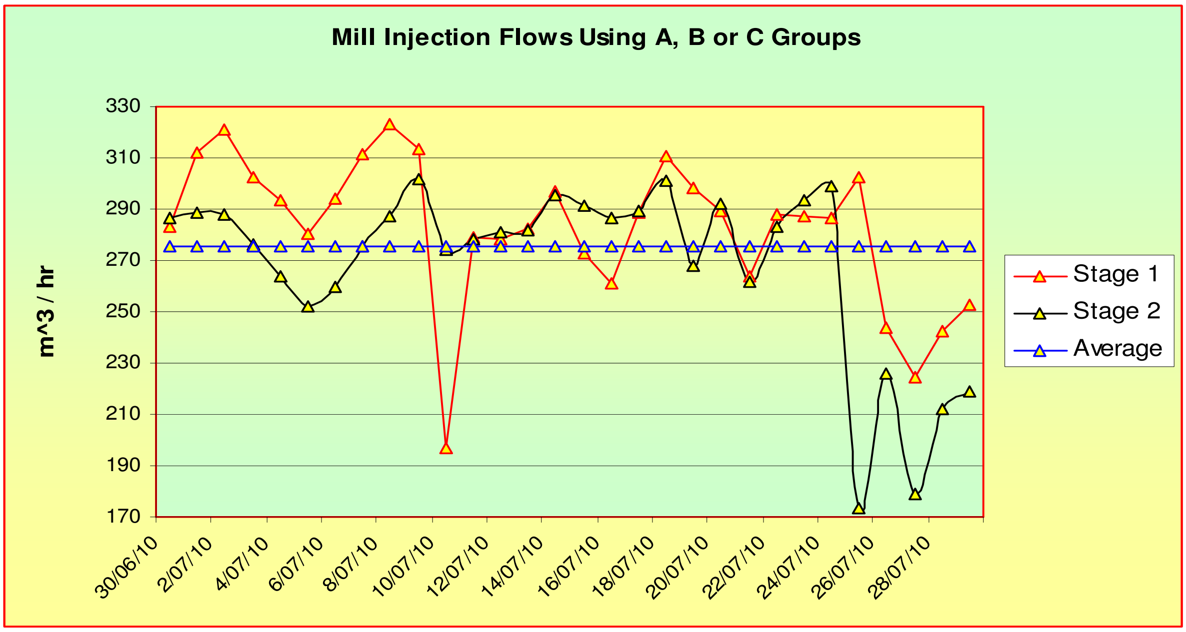


Chart 5.2 Stage 1 and 2 Mill Injection Flows for a 1 month period

Pump Shaft deflection (See Appendix for calculations involved)

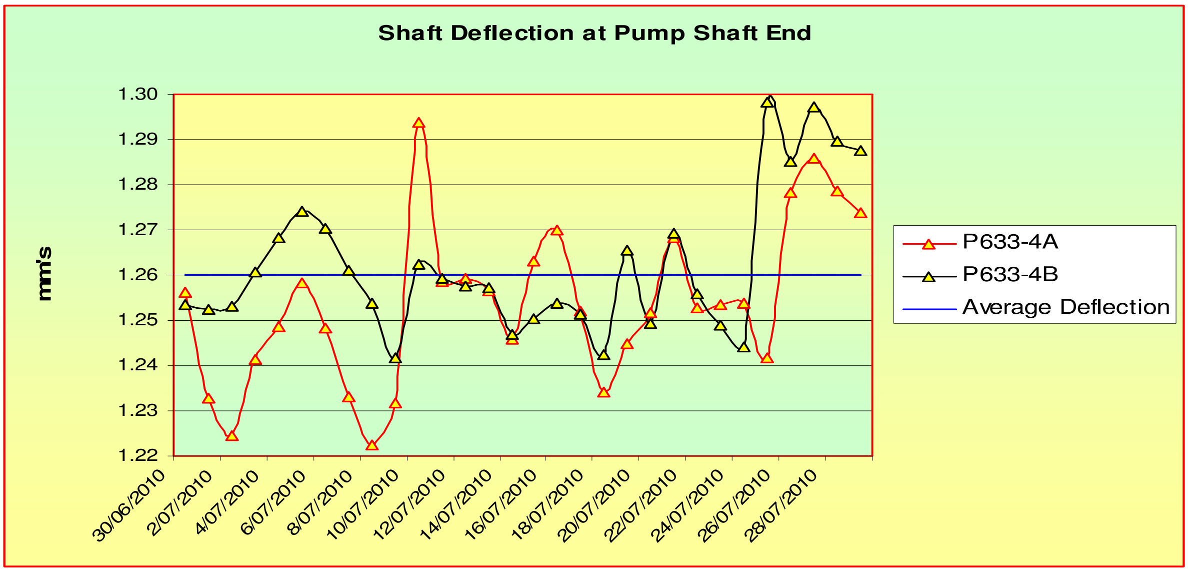


Chart 5.3 Calculated Pump Shaft deflection for the 1 month period

Recommended Shaft deflection as per manufacturers specifications for a 8/6 LSA 25 is <0.5mm from the end of the shaft.

5.3.5 Mechanical Inspection on Gland Failure

Refer to Appendix F for full maintenance reports.

The maintenance reports which were conducted in response to gland failures involved the following checks.

- Stuffing box to shaft concentricity
- Bearing wear
- Shaft sleeve wear
- Gland water pressure checks
- Gland water strainer checks
- Impeller clearance checks
- General condition checks.

The results of these check found that mechanically the pumps are okay and that it is unlikely that any mechanical issues are causing gland failures. It is worth noting that one of the investigations noted that the shaft sleeve had been contacting the wear plate. This indicates that the shaft is deflecting..

5.4 Conclusions

It is important not to draw to many inferences from the collected data. The data which has been collected will be an important tool when conducting the root cause analysis. Potential causes which are brainstormed will require validation it is at this point that the data can be referred to, to assess the validity of the cause.

CHAPTER 6
APOLLO ROOT CAUSE ANALYSIS

6.1 Aims of Chapter

The specific aims of this chapter utilise an RCA process which will enable the best and most practical solution to be found. The RCA process to be followed is called Apollo. The Apollo root cause methodology explores the relationships between the cause and effects and continues until all plausible root causes are exhausted. The Apollo root cause methodology is a standard Rio Tinto procedure and is facilitated by a software program.

The Methodology simplified is as follows

- Incident report – this helps to define the problem
- Reality chart – This consists of brainstorming all possible causes.
- Solution generation – Finding solutions for all possible causes
- Solution selection – Grading the solutions until the optimum one is found

6.2 Incident Report

INCIDENT REPORT
Purpose: To investigate production losses relating to the Mill injection Pumps, not to place blame.

For Internal Use Only
Report Date: Jul. 30, 2010
Start Date: Jul. 25, 2010
Report Number: 001

I. Problem Definition
What: Repetitive Mill Injection Pump Gland Failures
When: 01/01/2008 till present
Where: Area 633 of the Rio Tinto Alcan Gove Alumina Refinery
Significance: High Significances (Revenue loss)
Safety: No Injuries
Environmental: No EHS events
Revenue: $10,000,000 over a 28 month period in production losses (Current Alumina prices)
Cost: Maintenance $207,000 over a 28 Month period
Frequency: Almost a daily occurrence

Table 6.1 Incident Report

6.3 Reality Chart

To conduct a Root cause analysis a team is required. To be effective the team needs to represent the full cross section of the refinery. In this case it is Operations, maintenance and engineering.

Team Members

Name	**Email**	**Member Information**
Damon Bishop	damon.bishop@riotinto.com	Rotating Equipment Engineer
Scott Smith	scott.smith@riotinto.com	Pump Crew Supervisor
Terri Dupe	terri.dupe@riotinto.com	Graduate Engineer
Dave Bennett	dave.bennett@riotinto.com	Mills Operations supervisor

Table 6.2 RCA Team

Refer to Appendix G for the completed reality chart

Reality chart Summary

The results of the reality chart indicate that the Root cause of the repetitive gland failures is principally due to shaft deflection which is resulting from the hydraulic imbalance in the pump. This cyclic shaft deflection is deforming the packing which is resulting in slurry exiting the pump due to the inability of the packing to seal. The Hydraulic imbalance is due to the pump being operated away from the B.E.P. **Secondary causes** which have also contributed include periodic gland maintenance not being performed. it has also been recognized that it may be worthwhile in examining alternative shaft sleeve material with the goal of extending gland life.

Table 6.3 Summary

6.4 Solution Selection

The Solution assessment chart Table 6.5 displays the potential solutions and ranks them as per the criteria listed. As is represented in Table 6.4 and 6.5 the installation of a stiffened shaft has been seen as the most comprehensive solution by the team members. This selection of this solution has been based on the following.

- Subject matter expertise in the group (50 years pump experience in the group).
- Failure investigations
- Data collected
- Calculations performed
- Literary and Background review

Primary Solution Causes	Solutions	Solution Owner	Due Date
Poor Shaft slenderness ratio	Install stiffened shafts	Damon Bishop	Aug 28, 2010

Table 6.4 Solutions Generated From RCA

SOLUTION ASSESSMENT REPORT

Summary

Cause	Solution	Comment	Criteria Total Cost Weight 2 Ranking 1 (Expensive) to 4 (Low-Cost) Score	Criteria Ease of Implementation Weight 2 Ranking 1 (Difficult) to 4 (Easy) Score	Criteria Probability of Recurrence Weight 2 Ranking 8 (98-100%) to 1 (0-2%) Score	Criteria Effectiveness Weight 3 Ranking 1 (Not Eff.) to 4 (Very Eff.) Score	Criteria Return on Investment Weight 2 Ranking 1 (<100%) to 4 (>1000%) Score	Total Score
Pump operating away from B.E.P	Install VSDs	To Expensive. Major Substation modifications to accommodate VSD's	1	1	5	3	1	25
Poor Packing Installation Techniques	Re- Training of Fitters	Fitters are trained	4	3	2	1	4	29
Work order cancelled	Re-Open existing work orders	Re-open Work order	4	4	3	2	4	36
Shaft Sleeve Material to soft	Examine different Shaft Sleeve Materials	Ceramic Shaft sleeve	4	4	2	1	4	31
Hi Pressure Pump restricting the Low pressure pump	Install VSD on Low pressure pump so as to be in tune	See Above	1	1	6	3	1	27
TKL pumps	Change make of pumps to Warman Pumps	Prohibitive costs involved	1	1	7	4	1	32
Excessive shaft overhang	Fit Stuffing box bearing	Unlikely to be a long term solution as bearing will wear in a slurry application	3	3	4	3	4	37
Poor Shaft slenderness ration	Install stiffened shaft	Install one then validate solution	2	2	8	4	3	42
Shaft Deflection	Install Stiffened Shaft	As above	2	2	8	4	3	42
Packing has no elasticity.	Trial different Packing	This has been done numerous times in the past with little effect	4	4	2	1	4	31
Incorrect Installation	Provide training to maint Personnel	Fitters well trained already	4	3	2	1	4	29
No Gland nip ups	Perform Nip ups	Daily Mill injection pump checks to be performed	4	3	4	2	4	36
Slurry Abrading Shaft Sleeve surface	Trial different shaft sleeve material	Ceramic Shaft sleeve installed in Nov 2009. Validate performance	4	4	2	1	4	31

Table 6.5 Solution Assessment

6.5 Solution Description

The current pump shaft installed in the mill injection pump can be seen in Fig 6.1 the shaft has the same nominal dimension for the entire diameter excluding the impeller plug. The Bearings are mounted on tapered adaptor sleeves and the sealing is a lip seal / labyrinth arrangement.

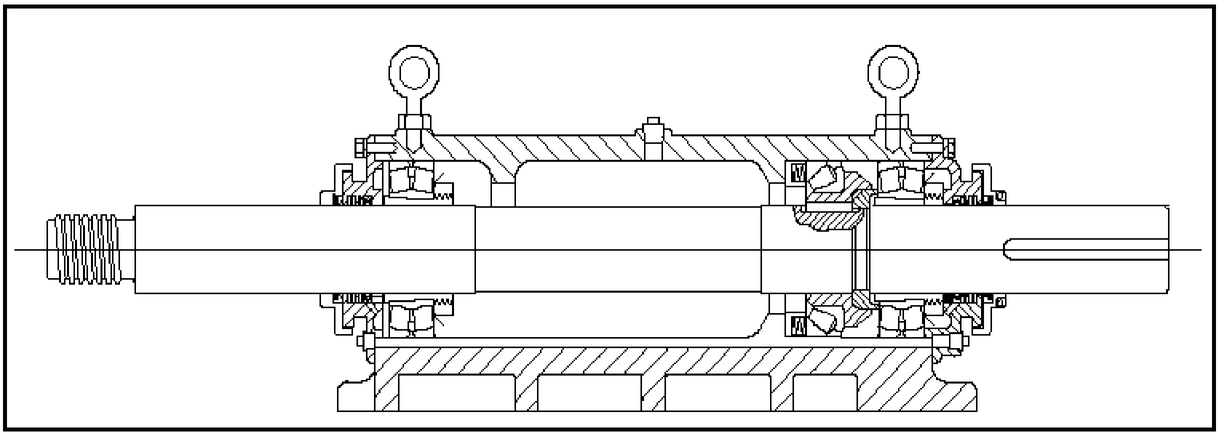


Figure 6.1 Existing Shaft Assembly

The stiffened shaft design as seen in Figure 6.2 displays a stepped shaft where the diameter of the shaft has been increased where ever possible. To achieve this the following features are enabled.

- Parallel bore bearings as opposed to tapered.
- Increased diameter between bearing to reduce shaft flex.
- Larger sealing faces
- Bearing housing base is thinner so as to enable larger bearings.
- Tapered bearings on the drive end to reduce the end float due to axial thrust.

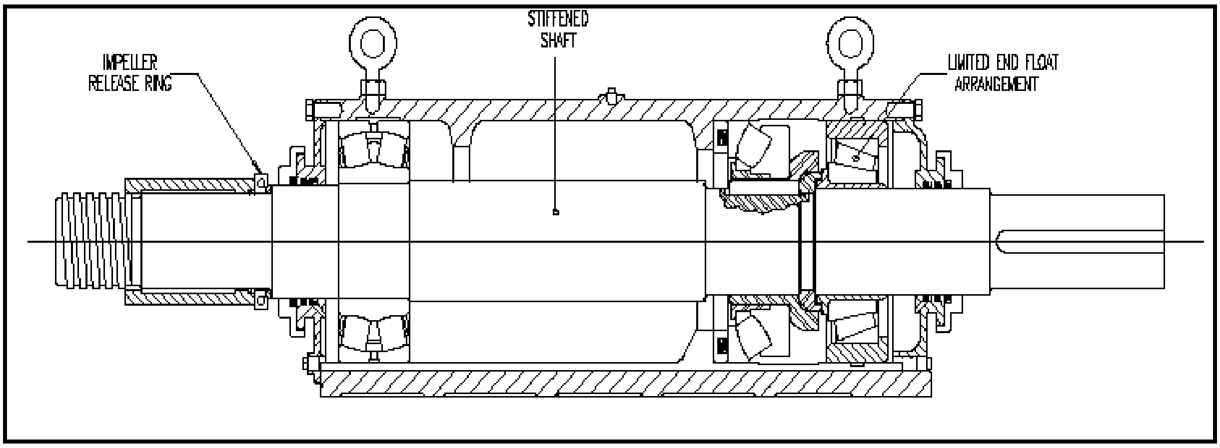


Figure 6.2 Stiffened Shaft Assembly

The calculated shaft deflection (See Appendix E for calculation details) for a Stiffened shaft has been determined for the same period that was measured for the straight shaft.

Chart 6.1 displays an average shaft deflection of 0.48mm as oppose to 1.26mm which was recorded for the straight shaft. The calculated 0.482mm is significantly lower than the straight shaft value and is below the recommended 0.5mm shaft deflection suggested by the pump manufacturers for optimum gland life. (LSAS Technical Booklet).

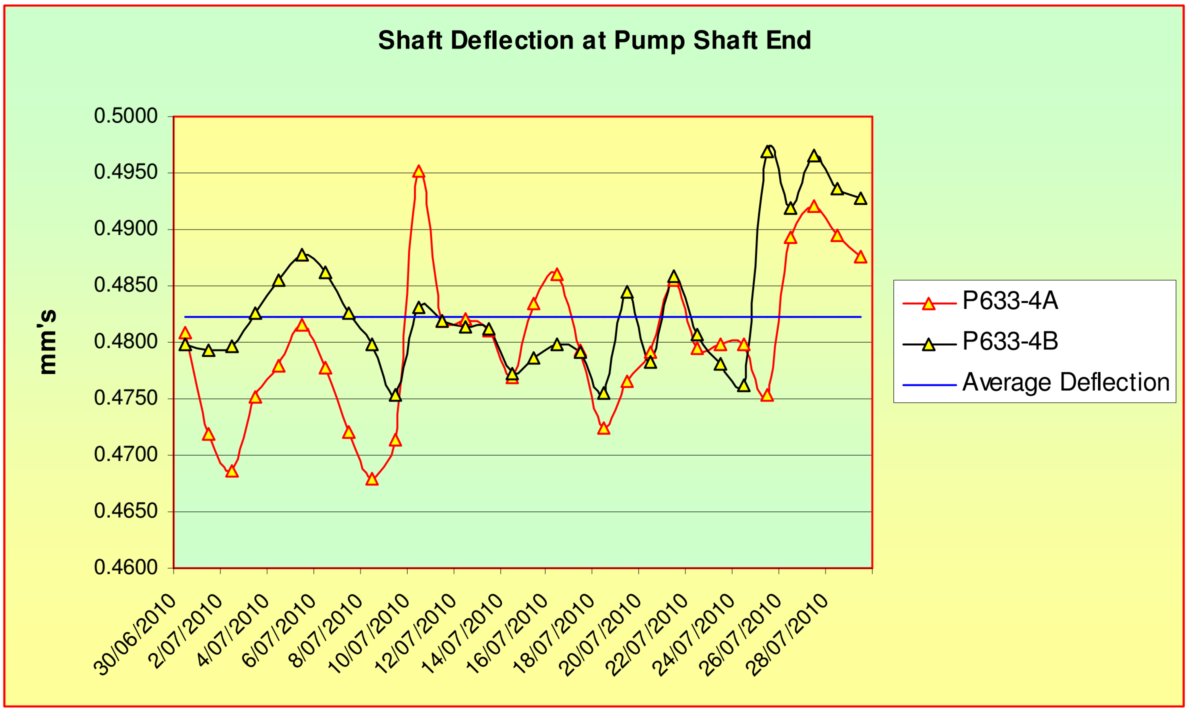


Chart 6.1 Calculated Shaft Deflection with stiffened assembly

A dynamic shaft analysis was carried out by the pump manufacturer using their software tool SLYSEL. The analysis summarised in Table 6.6 Revealed a similar result using slightly different data (They used theoretical flows where as we used actual) .

Shaft Deflection Table	**366m3/hr - Max**	**340m3/hr - Normal**	**206m3/hr - Min**
LSA 6x8/25 3-15/16" Standard Shaft	0.777mm	0.898mm	0.946mm
LSA 6x8/25 3-5/16" Stiffened Shaft Design	0.277mm	0.290mm	0.292mm

Table 6.6 KSB Pump Deflection Calculations

6.6 Conclusion

The solution which has been selected addresses the root cause but does not remove it. To remove the root cause it would be necessary to run the pump with less restriction however the requirements of the refinery do not allow this so it is not feasible. The advantage of the stiffened shaft proposal is that the root cause will be mitigated while not disturbing the shaft centreline, impeller hub dimensions, stuffing box dimensions or bearing housing dimensions. This reduces the cost of the upgrade considerably.

To implement the optimum solution it will now be necessary to perform a detailed financial analysis of the costs involved it installation of the stiffened shaft assemblies and the expected benefits that will come.

CHAPTER 7

SOLUTION IMPLIMENTATION AND VALIDATION

7.1 Aims of the Chapter

The specific aims of this chapter are to:

- Report on the accurate costing data for the installation of the mill injection shaft upgrade.
- Report on the process followed to gain acceptance from refinery management as to the benefits of the project and to consequently gain capital expenditure approval.
- Provide a plan for the installation of the Shaft Assemblies.
- Validate the Assembly once installed.

7.2 Mill Injection Pump Shaft Upgrade Cost

As earlier mentioned the pumps which have the worst performing gland MTBF are the older Kelly and Lewis A, B and C group pumps. The newer Warman D group pumps have an acceptable gland MTBF and do not require upgrading. Therefore a total of seven stiffened shaft assemblies will be required for purchase. The purchasing of an extra one will enable a rotating spare which can be available for installation in the event it is needed.

On investigating KSB pumps had provided a quote of $27,890 to supply the stiffened shafts (See Appendix H) with a lead time of 13 weeks.

The work required to install a stiffened shaft assembly includes the dismantling of the pump wet end and the removal of the belt drive pulleys, the shaft assembly can then be unbolted from the frame and removed. The re-installation is the opposite of the removal process. This task generally takes two fitters a full 12 hour shift to achieve with a crane group to assist.

	Singular	**Multiple**	**Total**
Purchase price for Stiffened Shaft assemblies	$27,890	x 7	$195,230
Installation costs for 2 Fitters	$200/hr	x 12 x 6	$14,400
Crane Requirements or 1 driver and 1 rigger	$300/hr	x 3 x 6	$5,400
		Total	**$215,030**

Table 7.1 Cost for Project

7.3 Acceptance From Refinery Management

To gain an in principle agreement to proceed with this project a presentation was conducted to the refinery management team (See Appendix H for power point presentation). The presentation communicated that this pump group was the worst performing on site with the greatest losses associated with it. Additionally the root cause was explained and supported with engineering data. The aligning of the pump manufacturers shaft deflection calculations with the project author gave further credibility to the potential success of the upgrading of the Mill injection pump shafts. A conservative net present value calculation was performed (See Table 7.2) which provided a return of $3,200,000 based on a 7% rate of return over 5 years.

Net Present Value H529 Mill Pump shaft assemblies		CEA
Total project cost (Est)	$	170,340.0
Benefits		
NPV (at 7 %)	$	3,207,562.1

Table 7.2 NPV

The reception was positive with the accord to immediately purchase one Stiffened Shaft Assembly from the maintenance budget with the other 6 to be purchased via the capital process. A $200,000 capital project was initiated (See Appendix H for completed paper work) and approved within 3 months.

7.4 Plan for Installation

The stiffened shaft assembly which was purchased using the maintenance budget was delivered and installed in P633-4B (worst performer) in early April (See Figure 7.1 and 7.2). This was advantageous as it enabled the solution to be validated and any modifications could be conducted on the remaining 6 assemblies.

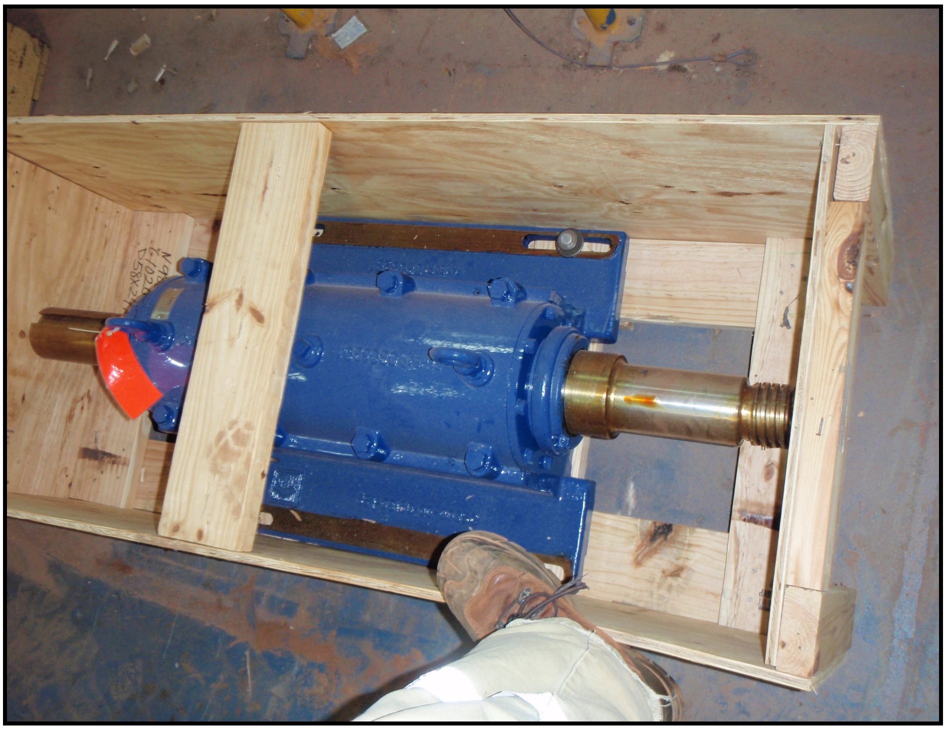


Figure 7.1 New assembly in box

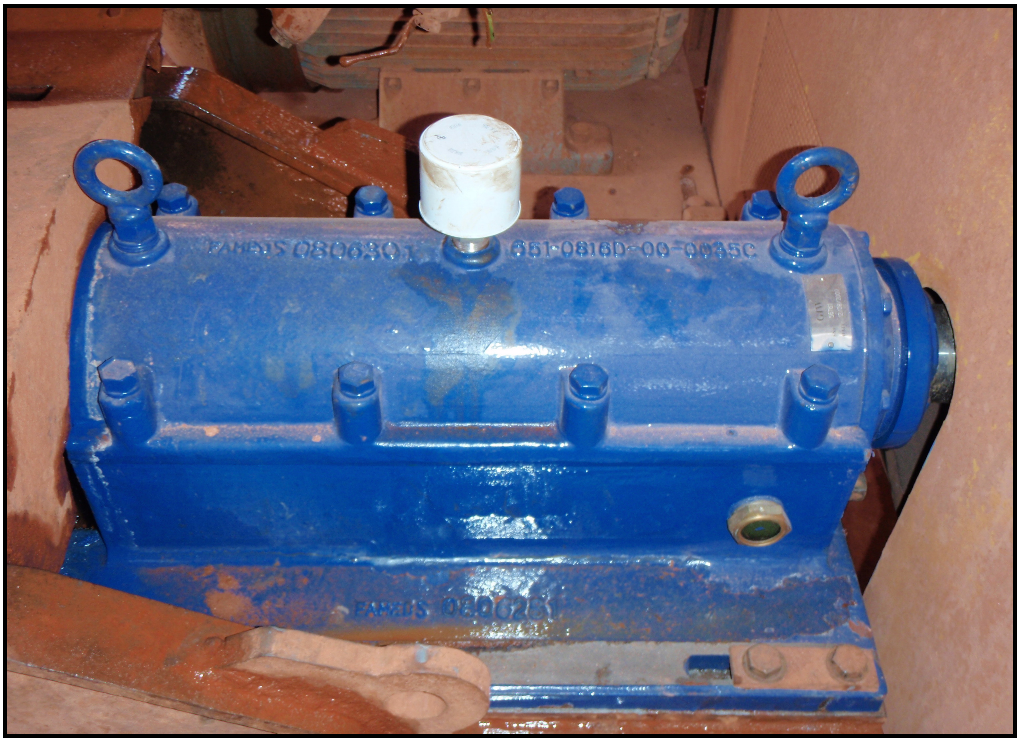


Figure 7.2 Installed Assembly in P633-4B

The 6 remaining shaft assemblies have had to be purchased via the capital budget which due to the process requirement takes 3 – 6 months. The shaft assemblies are due to arrive to site 01/09/2010.

In discussion with the Pump Crew co-ordinator it has been deemed to suitable to perform the shaft installations when the scheduled 3 monthly preventative maintenance tasks are performed. This way the compliance to the planned maintenance which occurs throughout the refinery will not be compromised. Of the A, B and C group pumps the low pressure pumps have the lowest MTBF and therefore are the logical place to start with the improvement work. Table 7.2 displays an approximate plan for the installation dates.

Plan to Achieve 90 day MTBF for Gland life (Mill Injection Pumps)												
	Mar-10	Apr-10	May-10	Jun-10	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10	Jan-11	90 Day Gland Life Acieved
Pump Upgrade												
Measurments and quotes												
Materials Purchased and Work Orders Raised (To increase laoding capacity)												
Installation P633-							4A & 5A	104C & 105C	5B	Complete		
Pump Conversion												
Mechanical Seal Installation (Possible												

Table 7.3 Plan for Installation

7.5 Validation of the project 6 months on

The stiffened shaft assembly which has been installed into P633-4B has significantly increased the gland reliability of the pump. As can be seen in Chart 7.1 previous MTBF for the gland on this pump was 19 days. As of 10/08/2010 the gland had not failed which gave it 120 day MTBF based on run time. This has given the project confidence that the implemented solution has directly addressed the root cause which is that the pump is operating away from the B.E.P and shaft is deflecting as a result.

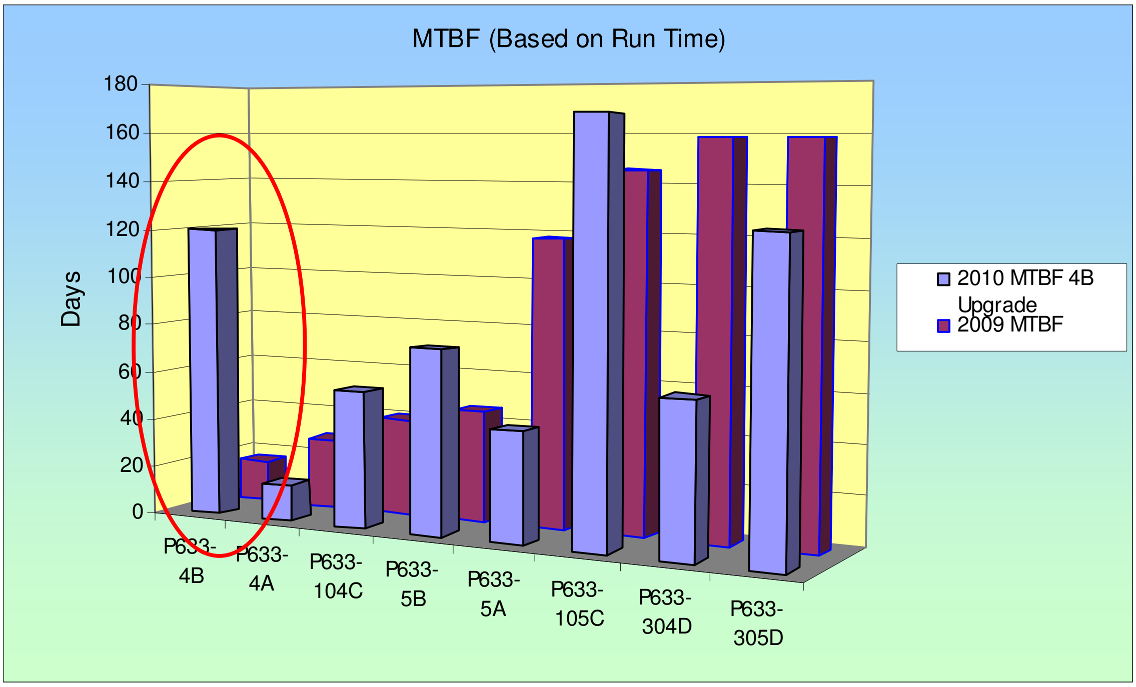


Chart 7.1 Comparison of MTBF for P633-4B before and After Shaft Upgrade

CHAPTER 8

CONCLUSION

8.1 Review of Project

8.1.1 Wins and Successes

By completing the objectives laid out in the project specifications the project has so far achieved its original goal which was to reduce the production losses due to gland failures to $0. Although only one stiffened shaft has been installed in this period the MTBF increase has allowed that the 75% required utilisation to be met which can be seen in Chart 8.1. Based on a continuation of these results the project cost of ~ $200,000 has been paid for with in the first month of the stiffened shafts installation. Besides the benefits of increased production the implemented solution also reduces the maintenance costs of the pump group and reduces the EHS risk associated with gland failures.

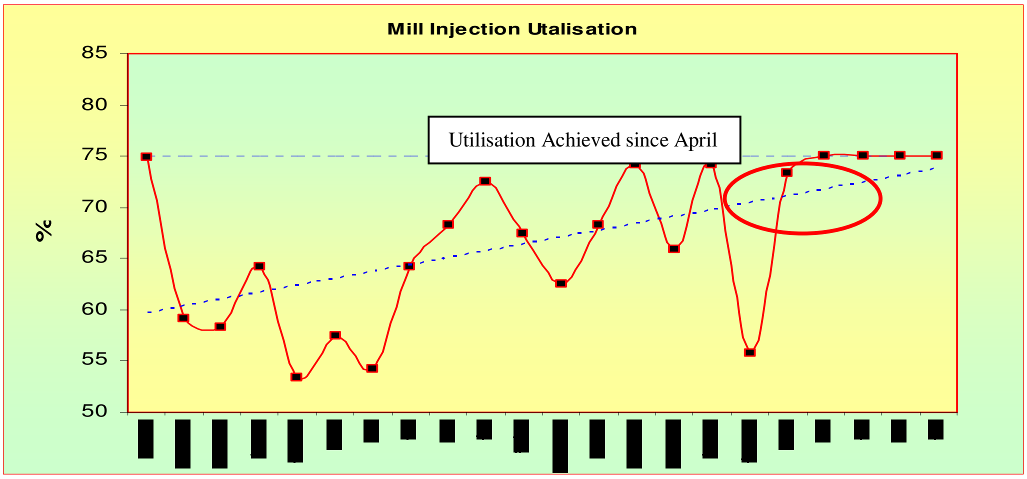


Chart 8.1 Mill Injection Utilisation

This project success can be attributed to good and clear communication between joint stakeholders in the project. The stakeholders being:

- Engineering who conceptualised developed and implemented the solution.
- Production who provided the financial resources for the purchasing of the solution.

- Maintenance who provided the labour and crane resources to install the solution.

8.1.2 Roadblocks and Delays

As earlier stated the production losses associated with the poor pump gland reliability on the mill injection pumps were in the order of $12,000 per day. Therefore the earlier that the stiffened shaft assembly was installed the quicker the return on the investment could be realised. From the agreement from the area superintendent to purchase of the first assembly to the installation took 6 months due to the following delays:

- The pump maintenance had exceeded their budget for that particular area and there was a reluctance from the area to use their budget to enable the purchase, this required clarification which took several weeks to resolve.
- Once the purchase was enabled there was a 14 weeks delivery time (partly due to the remote location).
- Once arrived sat in the warehouse for 10 weeks due to several factors which included lack of labour and crane availability for improvement work, on three occasions the planned work was bumped to enable breakdown work to take place.

8.2 Further Work to Complete Project

Following the Lean Six Sigma Methodology there are six stages of an improvement project, they are as follows

- Define
- Measure
- Analysis
- Improve
- Control
- Validate.

Relative to this project we are still in the improve stage where the implementation of the solution is taking place. Apart from the installation there are the following change management tasks need to be completed.

- Updating of the spares inventory to reflect the change.
- Communication and training to the maintenance personnel concerning the different impeller clearance requirements and bearing configurations.
- Obsolescing of the previous shaft assemblies

Further to this it will be important to close the project with a validation of its success which should be presented to the people responsible for the allocation of the required resources. This way the positive return on the invested funds can be confirmed and will give confidence towards the securing of funds for future reliability projects.

8.3 Further Benefits and Opportunities

Over the 30 period that this refinery has been in operation many of the original pump operating points have changed due to optimisation or expansion projects. Consequently many of the pumps are operating away from their B.E.P and experiencing hydraulic imbalance. One of the tools developed in this project is a shaft deflection calculator (Appendix E). Provided the dimensional features of the pump and flow characteristics are known the shaft deflection of any pump can be measured and compared against the manufacturer's specifications. This tool can now be applied to other pump groups which are experiencing the same symptoms that have been experienced by the mill injection pumps.

Further to this now that the shaft deflection on the mill injection pumps has been addressed former projects which have previously been unsuccessful can now be implemented with the objective of further increasing the gland life or reducing the parasitic water ingress into the product from gland flush. These projects could include mechanical seal conversion or for the purpose of reducing gland water the installation of a grooved flow restrictor.

8.4 Closing

The completion of this project has put to bed a long running reliability issue which has cost the refinery significant losses. It is the author's belief that the main reason this issue had never been solved previously is that although there is evidence to suggest that shaft deflection had been identified as a cause the only solution which had been seen as possible to mitigate it was to replace the pumps with an alternate design. This solution would entail the re-design of this area of the refinery due to the piping, pumping and plinth modifications to adapt to the new pumps. This work could have cost upwards of $5,000,000 to implement and then potentially still had the same reliability issue at the end of it. The modification of the pump which the project implemented was never previously considered and possibly not thought possible. Careful adherence to the defect elimination process has enabled the previously hidden solution to be exposed.

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Appendix A

University of Southern Queensland
FACULTY OF ENGINEERING AND SURVEYING

Eng4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **Damon Thomas BISHOP**

TOPIC: Improving Pump Gland Reliability

SUPERVISOR: Chris Snook

SPONSORSHIP: Rio Tinto Aluminium

PROJECT AIM: To investigate the process parameters which contribute to poor pump gland performance in the mill injection area and implement appropriate corrective actions which will provide an acceptable MTBF.

PROGRAMME: **(Issue A, 3rd March 2010)**

1. Research slurry pump sealing in industry (preferably the Alumina industry) with respect to designs, performance and reliability.
2. Investigate previous improvement projects which have been previously performed on this pump group.
3. Collect and analyse the data concerning the “cost to the business” that have resulted in the mill injection pumps poor gland performance. An example of this data is lost production tonnes, maintenance costs and EHS events.
4. Develop an evaluation plan for the collection and monitoring of historical and current data concerning the gland performance on the mill injection pumps. An example of these data is MTBF, gland water use, flow and pressure data.
5. Analyse the field data for the purpose of isolating the root cause or causes.
6. Develop potential solutions to mitigate the root cause and present recommendations to management for approval. Provide cost estimates, benefits and time lines.
7. Submit an academic dissertation on the research.

As time and resources permit.

8. Implement solutions by way of co-ordinating improvements with the Maintenance Co-ordinators, Planners and Area Production personnel.
9. Validate solutions through a continuation of monitoring the field data.

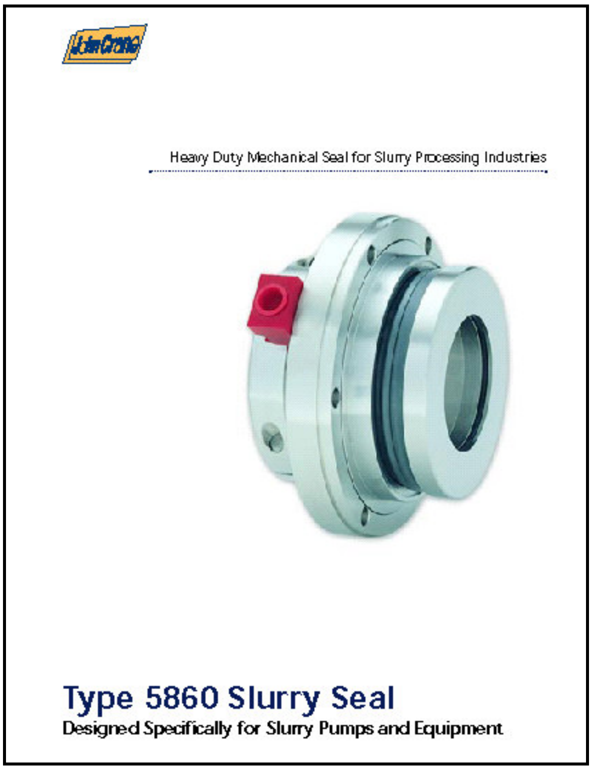
AGREED ___Approved___ (Student) _Approved__ (Supervisor)

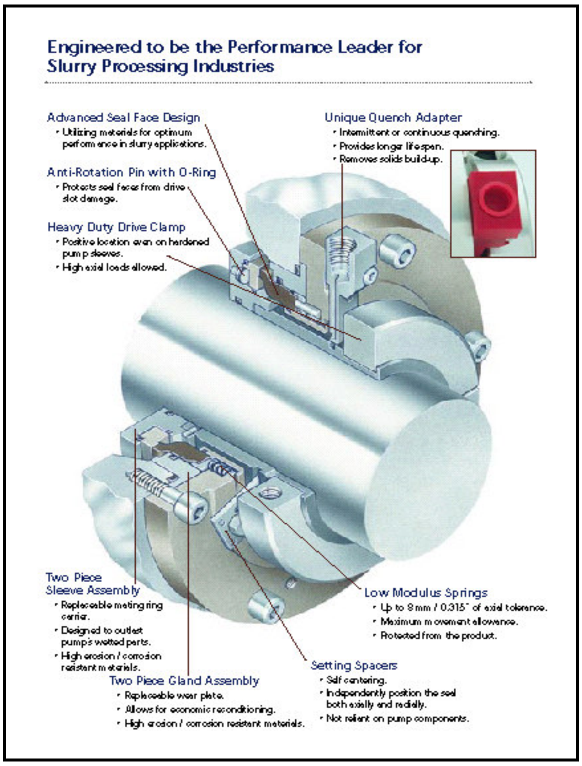
Date : / / 2010 Date : / / 2010

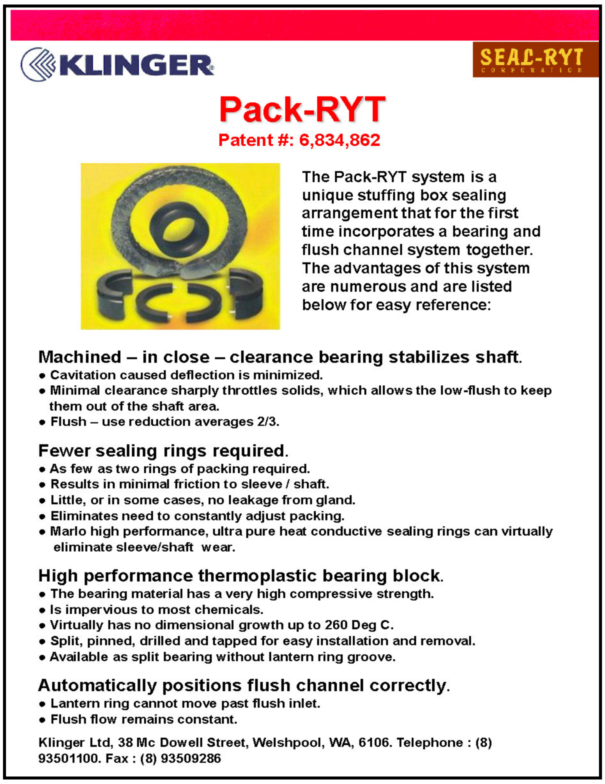
Examiner/Co-examiner:_______Approved___________

Appendix B

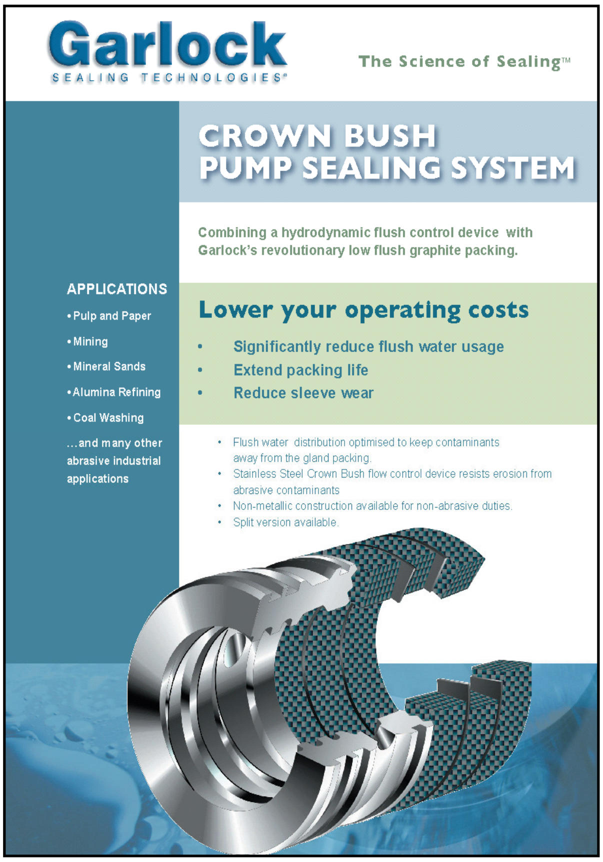
Industry Products to improve Gland Reliability







CBC
BEARINGS
POWER TRANSMISSION
Quality Endorsed Company
GLAND FOLLOWER
What is it?
The Gland Follower is a hydraulic method of compressing gland packing on rotating shafts.
The Gland Follower is a 'must have' product in order to eliminate workplace health & safety issues associated with current maintenance / operational procedures.
The Gland Follower is designed to fit into a pump application without modifying any other parts.
The unit is split into two pieces for ease of installation, avoiding costly downtime.
Applications
The Gland Follower is suitable for:
Centrifugal Slurry Pumps
Diaphragm Pumps
Reciprocating Pumps
Rotating Pumps
Valves (with gland boxes)
Why is it needed?
Traditionally the gland packing was compressed by tightening nuts, which forced the gland follower into contact with the packing until the flow of "liquid" is reduced to the required rate. This involved working around a rotating shaft with its inherent Workplace Health & Safety issues.
The Hydraulic Gland follower allows the operator to adjust the compression of the sealant packing from a safe distance away from both the rotating shaft and any dangerous product they may be pumping, reducing the risk of workplace health & safety issues occurring.
ISO 9001:2000 SGS
technofast
precision engineered solutions



Garlock
SEALING TECHNOLOGIES
The Science of Sealing™
CROWN BUSH
PUMP SEALING SYSTEM
Combining a hydrodynamic flush control device with Garlock's revolutionary low flush graphite packing.
APPLICATIONS
• Pulp and Paper
• Mining
• Mineral Sands
• Alumina Refining
• Coal Washing
...and many other abrasive industrial applications
Lower your operating costs
• Significantly reduce flush water usage
• Extend packing life
• Reduce sleeve wear
• Flush water distribution optimised to keep contaminants away from the gland packing.
• Stainless Steel Crown Bush flow control device resists erosion from abrasive contaminants
• Non-metallic construction available for non-abrasive duties.
• Split version available.

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Engineering Products Limited
About Us | Contac
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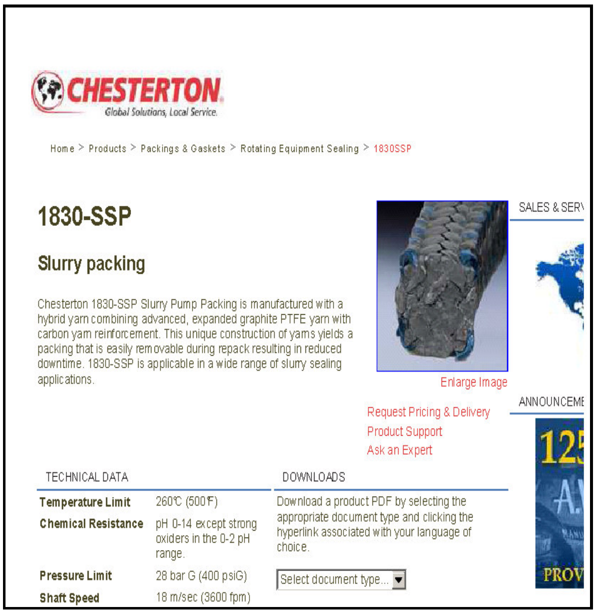
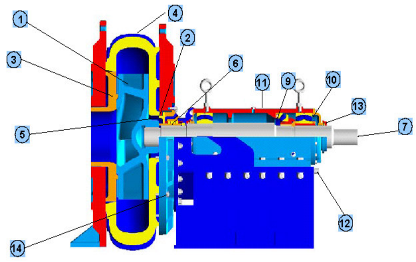
Home | SpiralTrac™ Environmental Controller | Version P | Version P Insert | Version N | Version F | Version D | Version C | SpiralTrac™ Adaptor
SpiralTrac™ Version P Insert
With SpiralTrac
Standard Configuration



CHESTERTON
Global Solutions, Local Service.
Home > Products > Packings & Gaskets > Rotating Equipment Sealing > 1830SSP
1830-SSP
Slurry packing
Chesterton 1830-SSP Slurry Pump Packing is manufactured with a hybrid yarn combining advanced, expanded graphite PTFE yarn with carbon yarn reinforcement. This unique construction of yarns yields a packing that is easily removable during repack resulting in reduced downtime. 1830-SSP is applicable in a wide range of slurry sealing applications.
Enlarge Image
Request Pricing & Delivery
Product Support
Ask an Expert
TECHNICAL DATA
Temperature Limit 260°C (500°F)
Chemical Resistance pH 0-14 except strong oxiders in the 0-2 pH range.
Pressure Limit 28 bar G (400 psiG)
Shaft Speed 18 m/sec (3600 fpm)
DOWNLOADS
Download a product PDF by selecting the appropriate document type and clicking the hyperlink associated with your language of choice.
Select document type...
SALES & SERV
ANNOUNCEME

GIW Model WBC Pumps

Low Maintenance, Severe Duty, Abrasion Resistant



Wear Parts

1. Impeller is designed for wear-resistant operation in highly abrasive slurries using GIW's flow simulation computer program.
2. Two aramid gaskets aid in the removal of the impeller.
3. Replaceable suction liner facilitates pump internal inspection and minimizes wear part usage cost. Liner can be rotated at intervals to increase wear life.
4. Pump shell is computer designed to optimize wear and efficiency.

Pump Seal

5. Replaceable wear plate maximizes stuffing box life.
6. Shaft sleeve with fused carbide hard coating to maximize packing life.

Mechanical End

7. Robust stiffened shaft to improve the wear life of the mechanical end and stuffing box.
8. Impeller release ring for easy impeller removal. Standard on all larger pumps.
9. Spring retainer ring locates the thrust bearing pre-load springs for correct axial thrust load.
10. Radial bearings are a heavy duty, self-aligning, double-row, spherical roller-type design. Limited end float is available for high pressure applications.
11. Split-cartridge bearing assembly offers ease of inspection and maintenance.
12. Accurate impeller clearance adjustments are easily made with the adjusting screw.
13. Labyrinth seals protect bearings.

Quick Alignment

14. Rabbet fits machined in the pedestal support the hub plate and shell to provide component alignment.

Interchangeability

To optimize wear life and efficiency, various hydraulic design and material options can be used on the same mechanical end.

PULSARLUBE M

Pulsarlube ML500 (500cc Automatic Grease Lubricator)

General Description

Pulsarlube ML500, a newly developed single point automatic grease lubricator, is primarily designed to ensure reliable lubrication of large size (>102mm O.D.) bearings commonly found in mining, cement, and steel industry. It is recognized that a common 125 or 250cc SPL unit does not have sufficient volume of lubricant required for large size bearings. Pulsarlube ML500 has a capacity of 500cc grease volume which meets the volume requirement specified by a bearing or equipment manufacturer.

It consists of a vertical feed pump, motor/gear set, and Microprocessor control system, which delivers an outstanding operating pressure of 280 psi, 20Kg-f/cm². For a cluster of bearings in close proximity or large size electric motor bearings, it can be also used as a multi-point lubricator by means of remote installation with a standard divider block.

The lubricant is supplied in customized 500cc grease pouch. Grease pouch and battery pack are replaceable in one package called **"Service Pack"** It consists of 5 different types of standard grease with either a standard battery pack or high performance lithium battery pack (optional), depending on the requirement of application. It offers a unique, selectable, 8 different dispensing rates from 1/2(Half) to 24 months in a single unit.

Special Features

New Pulsarlube ML500 has following features newly added:

Auto Locking Mode:	This function is provided to confirm that the unit MUST operate as per user setting in full period of service. It prevents a possible mode change by unintended (or erroneous) pressing keypad when the unit is still operating. When all modes are completely set, ML500 unit automatically locks keypad after 30 seconds and a "Lock Icon ( )" will pop-up on LCD. Once activated, the unit will not accept any input by pressing keypad. To unlock the keypad and go back to installation mode, simply press the "Mode" button for 2 seconds until Lock Icon disappears.
Low Battery Sensing:	A Red LED blinks every second when low battery exists.
Daily Dispensing Rate Display:	Once Auto Locking Mode is activated, the selected daily dispensing rate will start blinking on LCD until the dispensing period expires. Please refer to the chart in "**Lube Cycle and Dispensing Volume**" section of Specification below.

Pulsarlube ML500 Battery Selection Guide

	Alkaline Battery (Standard)	Lithium Battery (Option)
Temperature	14°F ~ 122°F (-10°C ~ +50°C)	-40°F ~ 140°F (-40°C ~ +60°C)
Back Pressure	280psi or less	Handles greater than 280psi
Divider Block	N / A	Upto 8 points
Distance	10ft or less for remote installations	Handles greater than 10ft / line for remote

Appendix C

Previous Improvement Projects

Pump Maintenance Meeting 36

(Week 18)

Subject: Pump Maintenance Strategy

Date: 05/05/04

Time: 1.00 pm

Location: Maintenance Planning Conference Room

Attendees: Aaron Edwards, D Mcdermid, Max Murdy, A Fleming

Minutes: A. Edwards

<u>Minutes of Meeting</u>

<u>EHS</u>

<u>First Priorities:</u>

GOV04050015 – Cut to right hand index finger.

<u>PERSONNEL ISSUES</u>

Pump Crew
Graeme Bean - A/L - 24/04/04 - 05/05/05
Skin Chessels – L/S 29/05/04 – 10/08/04
- A/L 01/08/04 – 26/08/04

Machine Shop
Pop Reardon - LSL - returns 24/05/04
Rick Hutchinson – A/L 28/04/04 – 06/05/04

<u>KPI</u>

KPI (weekly) – Week 3, 2004	**Measurement**	**Target**	**Compliance**
EHS - Injury, Enviro, Loss	1	0	No
5S	38	36	Yes
Work Backlog	Last: 2830 hrs This: 3043hrs	2000-2500hrs	No
% Planned work completed (schedule)	61	65%	No
% Planned Hrs of available Hrs	54	65%	No
Opportunity loss – pump failure	Mill Injection 1170T (	0 Reported	Yes
Continuous improvement projects	1	1 per quarter	Yes
Critical pump response time	12	12	Yes
Rotating spare schedule compliance	0	50%	No
Investigations completed	1	1 per week	Yes
		Score	**5/10**

<u>Unplanned Work - Critical Pump Reaction Time</u>

Criticality	Events	Response	Hrs
Critical A	2	Immediate	23
Critical B	7	Immediate	46
Critical C	3	Immediate	32
Critical D			
Unknown			

PRIORITY CALLED ON EQUIPMENT ID	PERSON RESPONSIBLE FOR CALLING PRIORITY	HOURS SPENT ON UNPLANNED PRIORITY	PUMP CRITICALITY
P633-5A	??	8	B
P633-105C	??	4	B
P633-104C	??	20	B
P646-6	??	4	C
P643-116	??	4	C
P633-5B	??	4	B
P633-4B	??	4	B
P633-4A	??	2	B
P633-101	??	8	A
P653-145A	S Savage	15	A
P633-5B	T Graham	4	B
P641-176	M Easterbrook	24	C

Percentage of "Rotating" Tasks achieved against plan = 0%

Maintenance Strategy

-

Continuous Improvement

- P633 Area continuous improvement project
  - Crown Bushes on order for trial in area – *expected to be delivered to Garlock week start 17/05*
  - Replacement of scaled pipework commenced by area. – *Parts have arrived and are being fabricated*

- Investigation completed for premature gland failure on pump P652-107A – Test points were installed last week. – *7 pumps are Part of Green Belt project – Dave Hill*
- Site investigation of gland water pressure – *Major continuous improvement project – AE to complete.*
- Review of PM's to remove invasive inspection of pumps and reduce number of PM's – *To be undertaken as a continuous improvement project – AE to complete by second quarter 2004.*

Major Priority Work

- Vacuum pump overhaul
- HX gearbox

General Business

- Area 643 pump and gland failures – *Follow up pressure checks once all stators replaced,*
- P646-22A/B Mechanical seal failure – *22a piping in place to convert to stuffing box, awaiting gland water supply to convert 22b*
- K&L 8*6 pumps – *Still awaiting bowls, on order since mid Feb. Will chase quote and lead time from GIW - AE*

The following issues were brought up at the meeting for further consideration:

- Millmax conversion of P633-4a – *Trial pump installed. Guard not refitted to pump (FP raised by area FP04040062)*

Next review meeting

Date: 19/04/04
Time: 10.00am

Location: Maintenance Planning Conference Room

Fortnightly Repacks for the Mill Injection Pumps

Model	EQUIP_NO	COMP_CODE	MAINT_SCH_TASK	JOB_DESC_CODE	SCHED_DESC_1	WORK_GROUP
K&L 6X8 LSA25	P633-104C	P100	0002	PM	GLAND REPACK	MPC
K&L 6X8 LSA25	P633-4A	P100	0002	PM	GLAND REPACK	MPC
K&L 6X8 LSA25	P633-4B	P100	0002	PM	GLAND REPACK	MPC
K&L 6X8 LSA25 HP	P633-105C	P100	0002	PM	GLAND REPACK	MPC
K&L 6X8 LSA25 HP	P633-5A	P100	0002	PM	GLAND REPACK	MPC
K&L 6X8 LSA25 HP	P633-5B	P100	0002	PM	GLAND REPACK	MPC

Packing Trial Tag to be hung from the pump

Trial Co-ordinator	:	**Damon Bishop (5718)**
Equipment Number	:	**P633-4B**
Trial Title	:	**Mill Pump Gland Optimisation**
Description of Trial	:	To Increase the gland life of the Mill injection pumps we are trialling 1830SSP packing.
Components being Trialled	:	1830 SSP Packing
Old Components	:	Graphlite Packing
Comments and Instructions.	:	**If Pump is re-packed please** » Retain old packing and deliver to Damon Bishop or Reactive supervisor. » Take note of Shaft Sleeve condition and give feedback. » Please re-pack with 1830SSP packing. The packing is available from the Reactive supervisors and only to be used on this pump.

Appendix D

Gland Water Requirements for Slurry Pumps

Nominal Shaft Size	Generic Bearing Number	Forward Movement Maximum		Forward Movement Minimum	
2 - 15/16	22217	0.059	(1.5)	0.020	(0.5)
3 - 15/16	22222	0.058	(1.5)	0.021	(0.5)
4 - 7/16	22226	0.071	(1.8)	0.024	(0.6)
5 - 7/16	22332	0.073	(1.8)	0.020	(0.5)
6 - 7/16	22336	0.072	(1.8)	0 023	(0.6)
7 - 3/16	22340	0.090	(2.3)	0.026	(0.6)
9	23252	0.096	(2.4)	0.024	(0.6)

Figure 15. LSA Shaft Forward Movement, in. (mm)

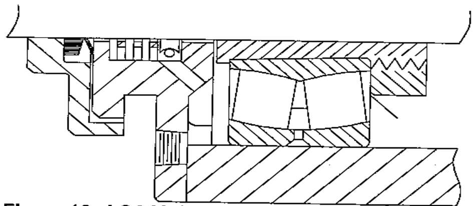


Figure 16. LSA V-ring Style Flinger Arrangement

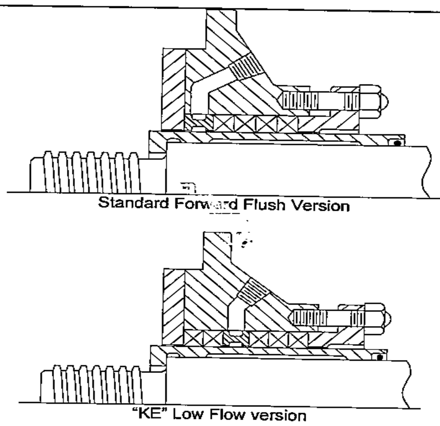


Figure 17. LSA Stuffing Box

Shaft Nominal Shaft Size	Typical Sleeve Outer Diam. [in]	[mm]	Maximum Sealing Water Requirements: Forward Flush [gpm]	[l/s]	KE [gpm]	[l/s]	Throat Bushing [gpm]	[l/s]
2 - 7/16	3.5	*88.9*	10	*0.6*	2	*0.1*	5	0.3
2 - 15/16	3.938	*100*	12	*0.8*	3	*0.2*	6	0.3
3 - 15/16	4.938	*125.4*	20	*1.3*	4	*0.3*	10	0.6
4 - 7/16	5.438	*138.1*	25	*1.6*	5	*0.3*	13	0.8
5 - 7/16	6.438	*163.5*	30	*1.9*	6	*0.4*	15	0.9
6 - 7/16	8.5	*215.9*	55	*3.5*	11	*0.7*	N/A	N/A
7- 3/16	8.5	*215.9*	55	*3.5*	11	*0.7*	28	1.7
9	10.5	*266.7*	85	*5.4*	N/A	*N/A*	43	2.7
10- 1/4	11.9	*303.2*	110	*6.9*	N/A	*N/A*	55	3.4
10- 1/4 Extra	14	*355.6*	150	*9.5*	N/A	*N/A*	75	4.7
11- 1/2	14	*355.6*	150	*9.5*	N/A	*N/A*	75	4.7
13	17	*431.8*	225	*14*	N/A	*N/A*	N/A	*N/A*

Figure 18. Stuffing Box Maximum Seal Water Requirements in gpm (l/s)

5.2.3 Shaft Seal Design

Shaft seal design of the slurry pump is controlled by the presence of solids and the availability of purge water. Two basic configurations exist for the Standard LSA: the stuffing box and mechanical seal.

5.2.3.1 Stuffing Box

The slurry pump stuffing box must, in most cases, be supplied with an external water flush to prevent the solids from entering the sealing area, where they would cause premature damage to the shaft sleeve.

The standard LSA stuffing box configuration is shown in Figure 17. Flush water is introduced forward of all packing to insure only clear water at the sealing surface. If flush water usage must be reduced, a KE version of the stuffing box is available as a standard option. In this case, two rings of packing are provided forward of the seal water ring to limit seal water usage. Seal water should be available at 10 psi (0.7 bar) above maximum pump discharge pressure, and in the flow rates shown in Figure 18. During operation, stuffing box purge water should be pressure controlled, not flow controlled. The flow out of the box should be adjusted to the minimum amount required to provide cooling. This often results in flow rates considerably less than those given in Figure 18, which are maximum requirements for worn in packing. Flow control of stuffing boxes is not recommended. It may result in abnormally high sealing pressures and lead to jamming of the packing, excessive heat and wear.

The standard stuffing box is constructed of gray iron. The standard shaft sleeve is constructed of steel with a flame sprayed, nickel-chromium, carbide coating approximately 0.04 inches (1.0 mm) thick.

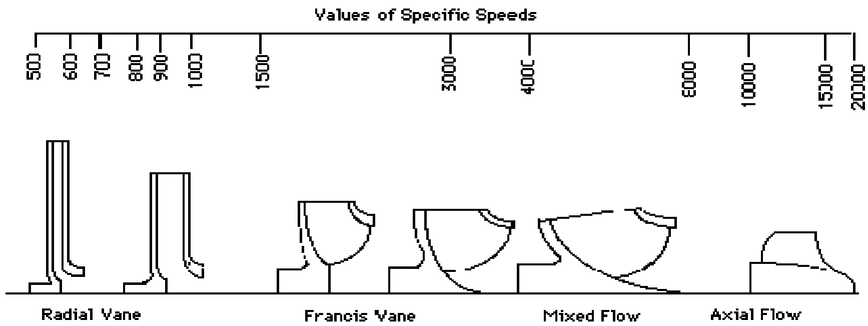
5.2.3.2 Mechanical Seals

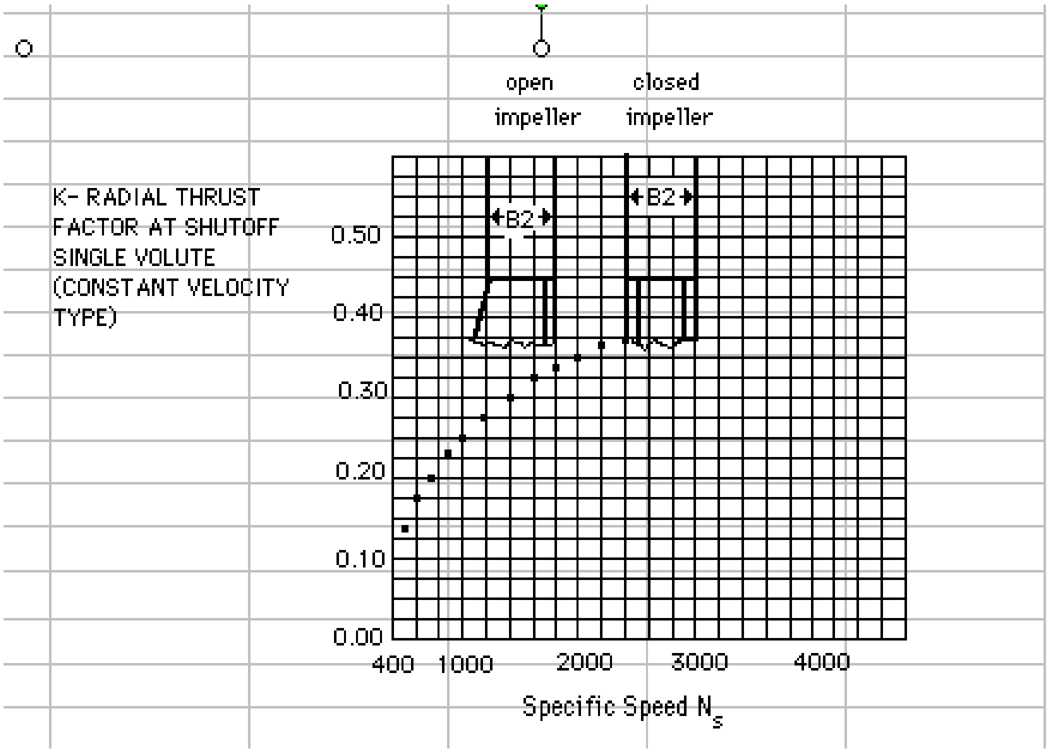
Many different mechanical seal designs exist, including models specifically developed for slurries. The correct seal type for any given application depends upon the nature of the slurry (solids size, concentration, etc...) and the mode of operation (continuous, intermittent, dry running, shock loadings, etc...).Mechanical seals for slurry operation should be resistant to clogging by precipitated slurries and to abrasion at all wetted surfaces. Where a continuous cooling flush is *not* applied, pressure reducing clearing vanes on the drive side of the impeller should be avoided due to the possibility of forming an air pocket at the seal during startup. The seal design must be such that it will receive sufficient cooling from the pumped fluid during normal operation. Previous in-plant experience is often the best guide to successful mechanical seal selection. If in doubt, consult your GIW / KSB sales office. The mating dimensions of the LSA pump in the seal area are shown in the dimensional tables section 9.3.

Appendix E

Shaft Deflection Calculations

Specific Speed		
Specific Speed Ns = (N x (Q^(1/2)) / (H^ (3/ 4)) / 1.9		
N = The speed of the pump in revolutions per minute (rpm.)	N	811
Q = The flow rate M³ /hr (for either single or double suction impellers) @ B.E.P.	Q	630
H = The total dynamic head in m's @ B.E.P.	H	42.9
	Ns	2307.28775





Bending Force Formula

S.G = Specific Gravity of the Liquid	S.G	1.824
H = Total head @ B.E.P. (Meters)	H	42.9
B2 = Width of Impeller including Shrouds (mm)	B2	150
D2 = O.D of the impeller (mm)	D2	635
Kq = 1- $(Q^2/Qn^2)^2$	Kq	0.989843179
K = Radial thrust factor 0.3 to 0.35 (See Chart)	K	0.38
Q = M^3 /hr actually Pumping	Q	200
Qn= M^3 /hr @ the B.E.P.	Qn	630
P = (Kq x K x H x S.G. x D2 x B2) / 9.81	P	2857.775408
W = Weight of Impeller Kg's	W	250
P = Kg's of Force generated	F	3107.775408

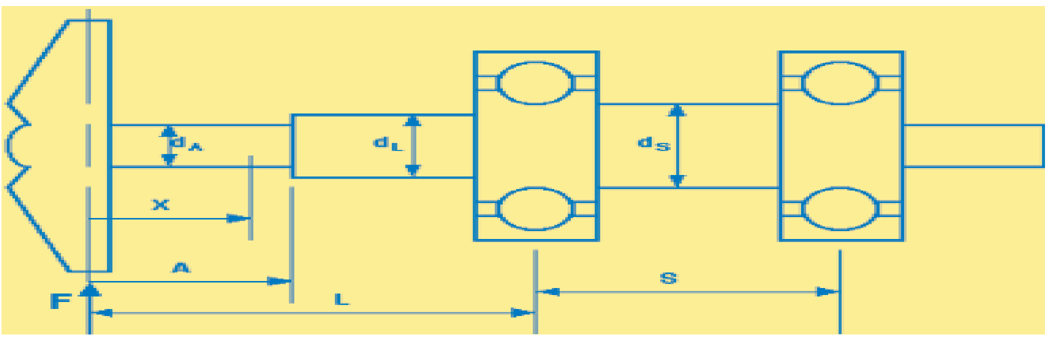
Shaft Deflection For Straight Shafts		
Y = (F x L^3) / (3 x E x I)		
F = Hydraulic Radial Imbalance, Kg's (In previous)	F	3107.775408
D = Shaft Diameter mm's	D	100.01
I = Moment of Inertia (π x D^4 / 64)	I	491.0702311
E = Modulus of elasticity of the shaft material (Kg's / cm^2)	E	2039432
L = Distance from the impeller centreline to the inboard bearing, mm's	L	500
Y = Shaft Deflection at the Impeller centreline mm's	Y	1.292961362

Shaft Deflection for Stepped Shafts

$$y = \frac{F}{3E}\left[\frac{L^3 - A^3}{I_L} + \frac{A^3}{I_a} + \frac{L^2 S}{I_s} + \frac{3X}{2}\left(\frac{L^2 - A^2}{I_L} + \frac{A^2}{I_a} + \frac{2LS}{3I_s}\right) + \frac{X^3}{2I_a}\right]$$

$$\text{where Moment of Inertia } I = \pi \times \frac{D^4}{64}$$

F = Hydraulic Radial Imbalance, Kg's (In previous)	F	3107.775408
A = Distance from the impeller centreline to the steps of the shaft, mm's	A	200
S = Span between bearing centrelines, mm's	S	600
Il, Im, In = Moments of inertia of the various diameters, mm's	Is	7853.981634
	Il	1885.74099
	Ia	491.0702311
X= Distance to Stuffing Box Front mm's	X	0
D = Shaft Diameters mm's	Ds	200
	Dl	140
	Da	100.01
L = Distance from the impeller centreline to the inboard bearing, cm's	L	500
E = Modulus of elasticity of the shaft material (Kg's / cm²)	E	2039432
Y = Shaft Deflection at X mm's	Y	0.494914524

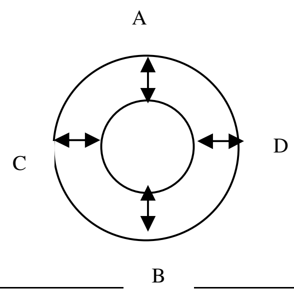


Appendix F

Mechanical Inspection Reports

<table>
<tr><td colspan="4">Kelly & Lewis Pump PM / Condition Report</td></tr>
<tr><td>Work order</td><td colspan="3">642510</td></tr>
<tr><td>Equipment No.</td><td colspan="3">P633-4b</td></tr>
<tr><td>Type</td><td colspan="3">6x8 top discharge</td></tr>
<tr><td>Checked by</td><td colspan="3">R. Whitham P.Fourie N. Finlay</td></tr>
<tr><td>Date</td><td colspan="3">21/04/10</td></tr>
<tr><td>Failure / date</td><td colspan="3">19/04/10</td></tr>
<tr><td>History</td><td colspan="3"></td></tr>
<tr><td>Root Cause</td><td colspan="3">Gland failure</td></tr>
<tr><td>Pump Criticality</td><td colspan="3">b</td></tr>
<tr><td colspan="4">Pump</td></tr>
<tr><td rowspan="2"><u>Suction Liner</u></td><td colspan="2">Replaced? Y/N</td><td rowspan="2">Condition (0 – 60%): 60%</td></tr>
<tr><td colspan="2">y</td></tr>
<tr><td rowspan="2"><u>Casing/Bowl</u></td><td colspan="2">Replaced? Y/N</td><td rowspan="2">Condition (0 – 60%): 30%</td></tr>
<tr><td colspan="2">n</td></tr>
<tr><td rowspan="2"><u>Impeller</u></td><td colspan="2">Replaced? Y/N</td><td rowspan="2">Condition (0 – 60%): 30%</td></tr>
<tr><td colspan="2">y</td></tr>
<tr><td><u>Suction Liner-Impeller Clearance</u>
To be checked before pump is pulled down.</td><td colspan="3">Max: 0.060” Dependent on end float

Adjusted: ……0.060”………</td></tr>
<tr><td rowspan="2"><u>Bearing Lifts</u>
Packing to be removed, drive uncoupled before tests. Max lift: .008”</td><td colspan="3">Inboard: 0.003”</td></tr>
<tr><td colspan="3">Outboard: 0.001”</td></tr>
<tr><td rowspan="4"><u>Seal condition</u></td><td colspan="2">Replaced? Y/N</td><td rowspan="2">Inboard: new style seals fitted to both inboard and outboard</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">Replaced? Y/N</td><td rowspan="2">Outboard:</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="4">Stuffing Box</td></tr>
<tr><td><u>Gland Configuration</u>
Please make a note of correct gland configuration.</td><td colspan="2"></td><td>No. of rings……2 l/ring 4…………
Lantern Ring
No. of rings…………6……</td></tr>
<tr><td rowspan="2"><u>Packing Type used</u></td><td colspan="2">Replaced? Y/N</td><td rowspan="2">1333-g</td></tr>
<tr><td colspan="2">y</td></tr>
<tr><td rowspan="2"><u>Shaft sleeve</u></td><td colspan="3">Size: 124mm</td></tr>
<tr><td colspan="3">Condition: new</td></tr>
<tr><td><u>Stuffing Box condition</u></td><td colspan="3">good</td></tr>
</table>

Stuffing Box Bore size Specification: Greater than 1mm on ∅ requires replacement.	**Size:** **Condition:** good	
Stuffing Box Concentricity about Shaft Sleeve		**A:** 20mm **B:** 20mm **C:** 20.5mm **D:** 20mm
Gland Water Pressure	10 atu	
Strainer Condition	good	
Flow restrictor size	12l/min	
Gland Follower condition	good	
Gland Studs	good	
Gland Water Supply Line Condition	new	

Scale Muncher

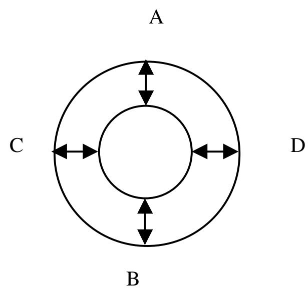
Attrition Plate to Cutter Clearance. *To be checked before pumps pulled down*		Recommended: 5.0mm Actual:……….. Adjusted:……………
Attrition Plate condition	**Replaced? Y/N**	
Cutter Tool condition	**Replaced? Y/N**	
Stub Shaft condition	**Replaced? Y/N**	

Belt Drive

Pulley – Driven	**Replaced? Y/N** n	good
Pulley – Drive	**Replaced? Y/N** n	good
Belts condition	**Replaced? Y/N** y	**Retention setting:** **Condition:** new
Guard Condition		

RIO TINTO ALCAN GOVE PUMP CREW

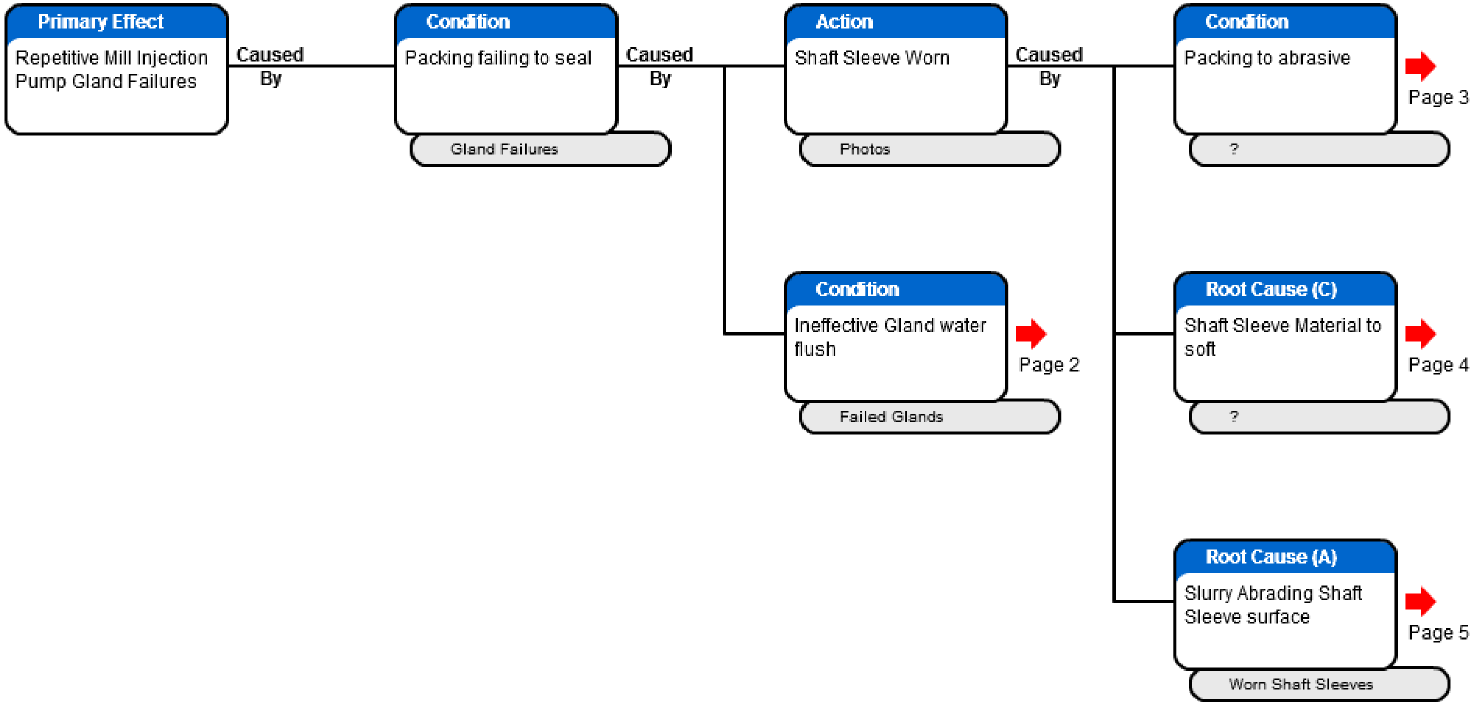
Pump Repack Report

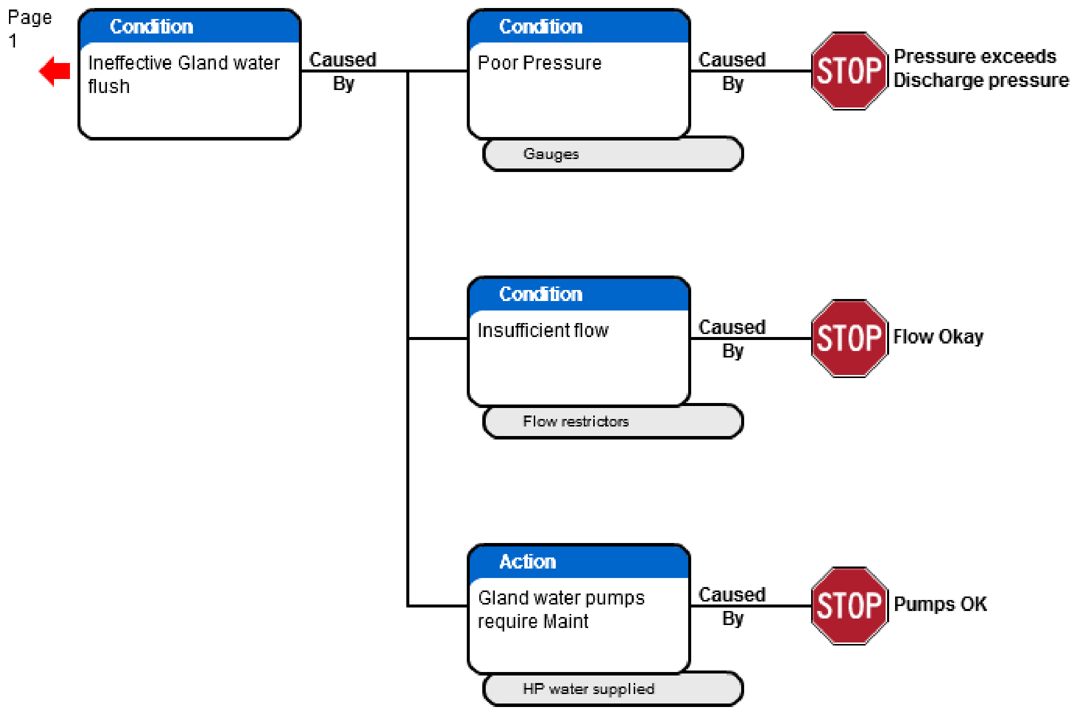
Equipment No.	**P633-4A**	
Type	**6X8 K&L**	
Checked by	**R WHITHAM**	
Date	**14/04/10**	
Failure	**GLAND**	
Failure date	**14/04/10**	
Operating history		
Root Cause	**PACKING**	
Pump Criticality	**B**	
Pump run time (from last failure)		
	Manufacturers / Alcan data	**Measurement / observation**
Gland configuration	**2 L/RING 4**	
Packing type	**1333-G**	
Shaft sleeve dia	**126mm**	**GROOVE UNDER W/PLATE**
Shaft sleeve surface roughness		**GOOD**
Scale build-up in stuffing box bore		**NIL**
Stuffing box bore dia		
Stuffing box concentricity about shaft sleeve		A: 19.5 B: 19.5 C: 20.00 D:20.00
Water sealing requirement	**12 L/MIN**	
Sealing water flow past throat bush		
Gland water pressure	**10 ATU**	
Pump discharge pressure		
Gland water flow rate at pressure		
Strainer condition	**GOOD**	
Restrictor flow rate	**12 L /MIN**	
Gland packing run-in		

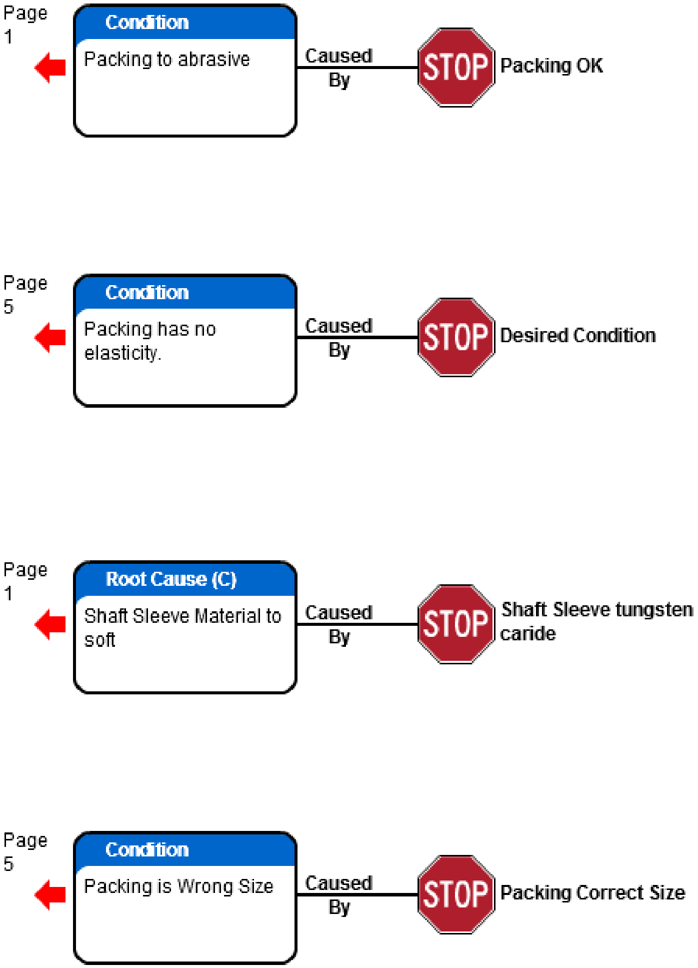
period		
• 1^{st} hour		
• 2^{nd} hour		
• 3^{rd} hour		
• 4^{th} hour		
Pump handover		
Comments	SHAFT SLEEVE STARTING TO GET GROOVE UNDER WEAR PLATE,PROBABLY NEED CHANGING OUT IN NEAR FUTURE,(4-6 WEEKS)	
Recommendations	PLAN TO C/OUT SLEEVE	

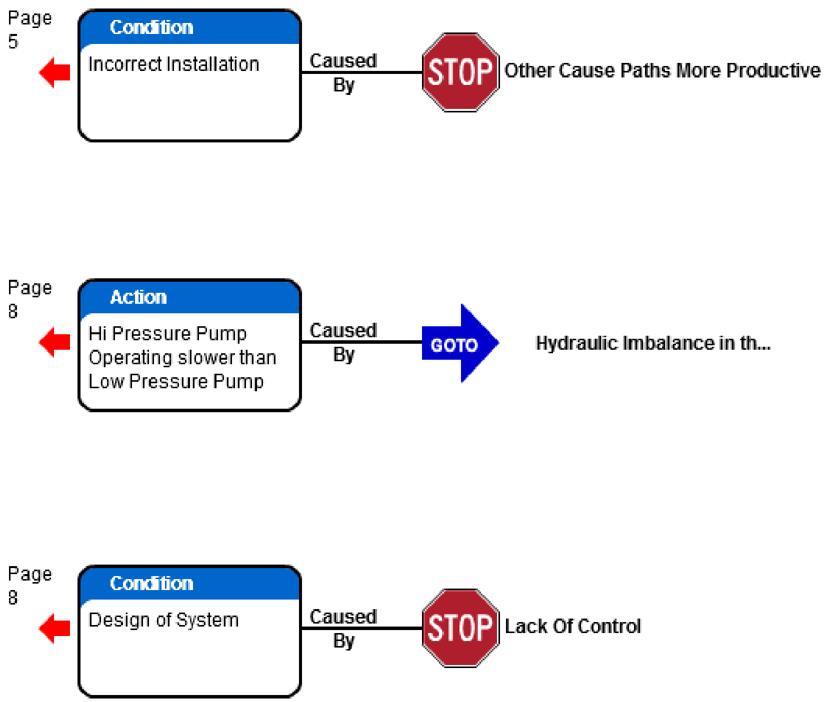
Appendix G

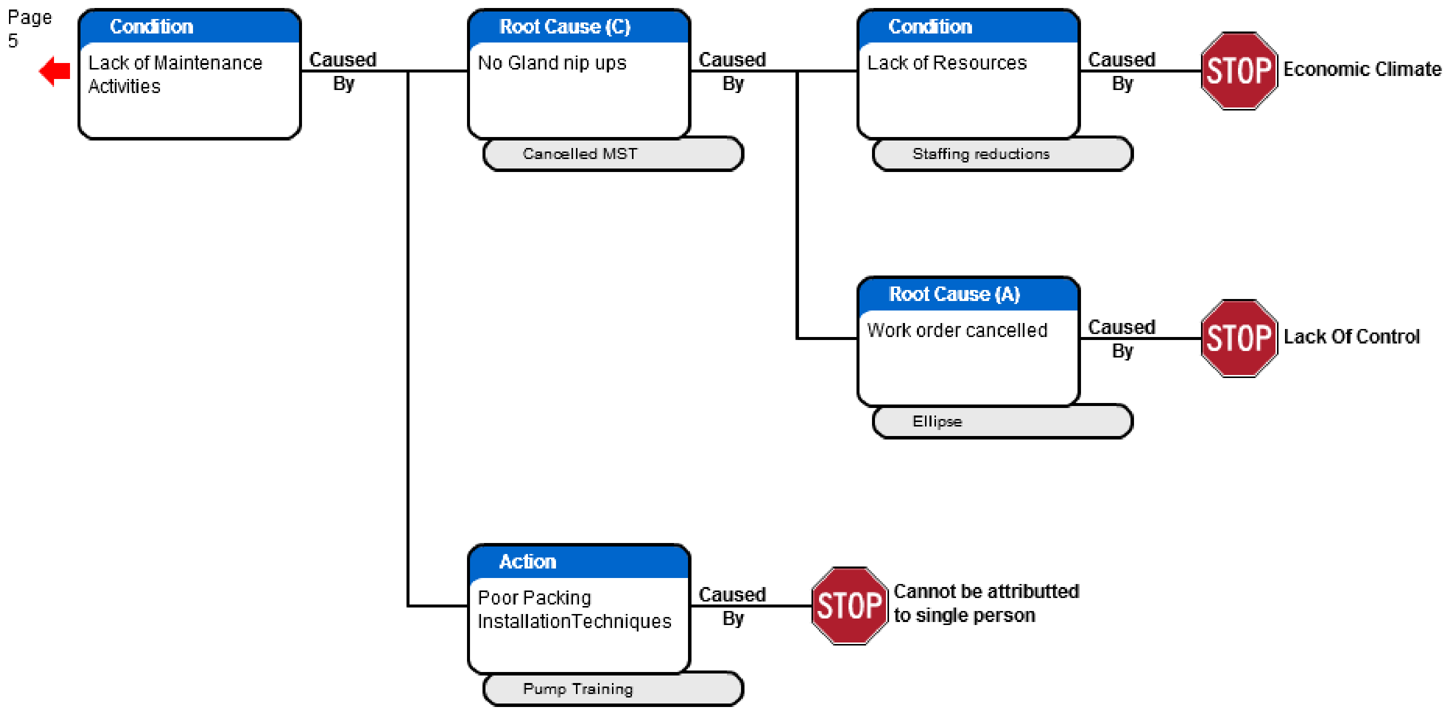
Reality Chart Summaries



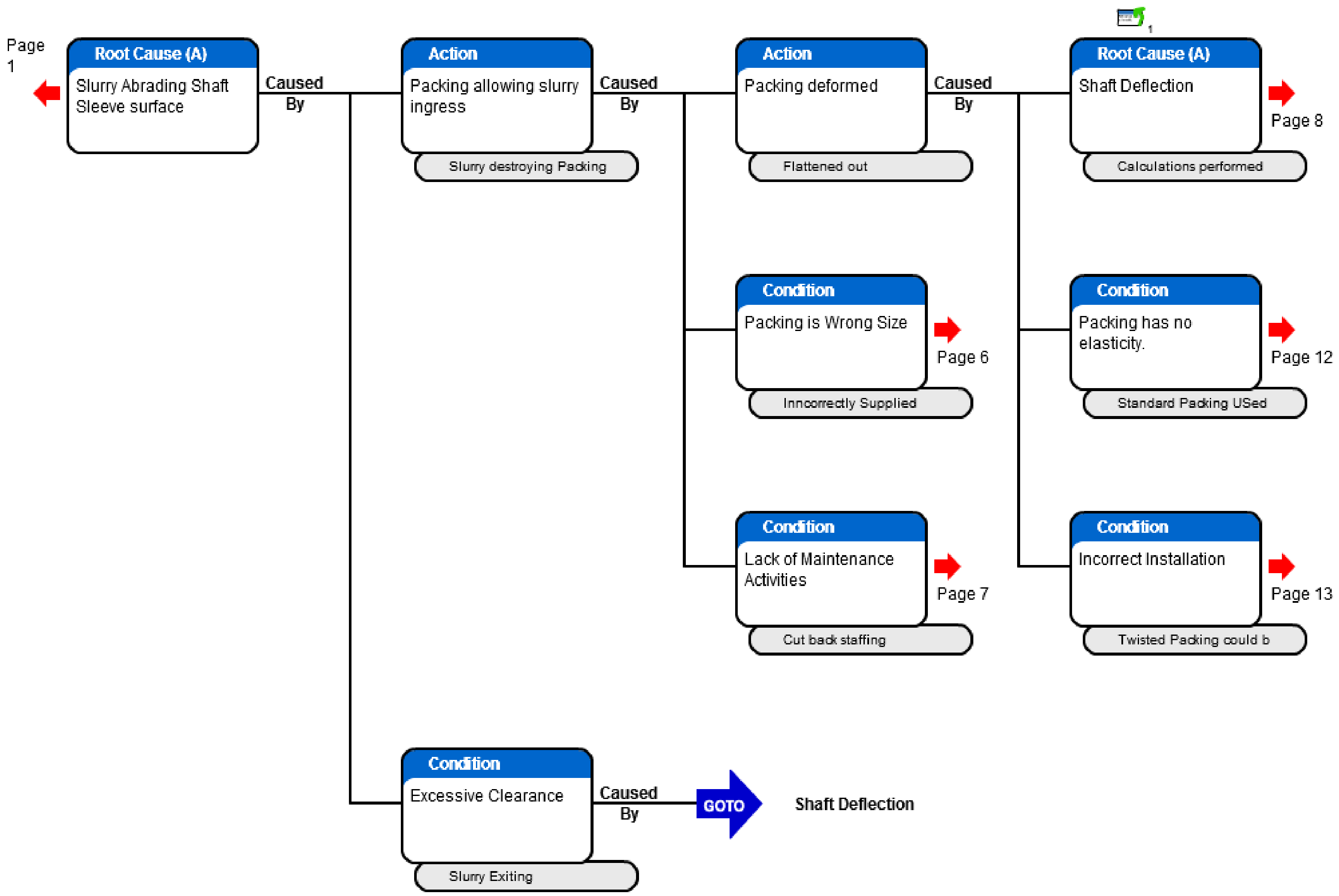

Page
1
Condition
Ineffective Gland water flush
Caused By
Condition
Poor Pressure
Gauges
Caused By
STOP
Pressure exceeds Discharge pressure
Condition
Insufficient flow
Flow restrictors
Caused By
STOP
Flow Okay
Action
Gland water pumps require Maint
HP water supplied
Caused By
STOP
Pumps OK

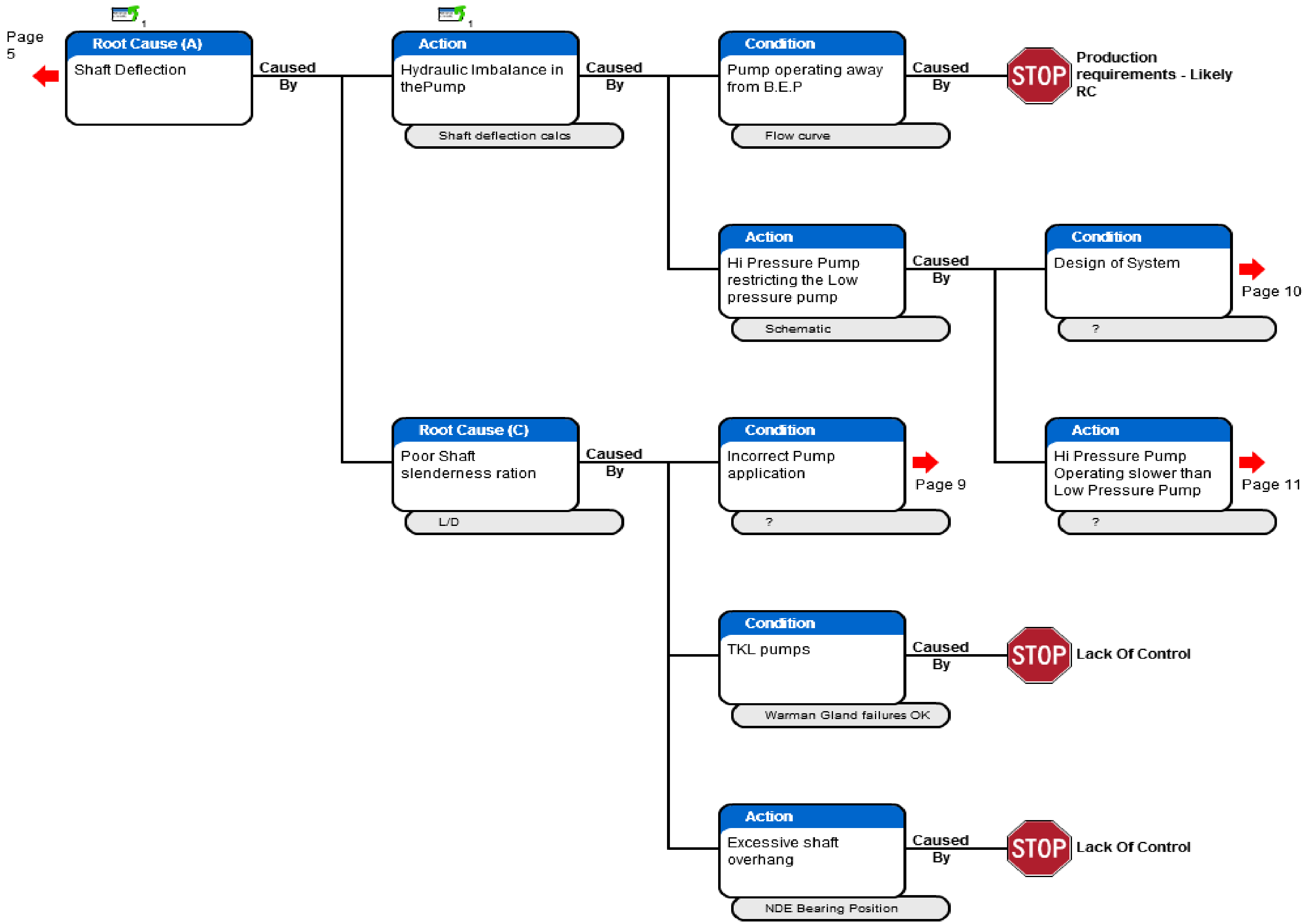

Page 1
Condition
Packing to abrasive
Caused By
STOP
Packing OK
Page 5
Condition
Packing has no elasticity.
Caused By
STOP
Desired Condition
Page 1
Root Cause (C)
Shaft Sleeve Material to soft
Caused By
STOP
Shaft Sleeve tungsten caride
Page 5
Condition
Packing is Wrong Size
Caused By
STOP
Packing Correct Size


Page
5
Condition
Incorrect Installation
Caused By
STOP
Other Cause Paths More Productive
Page
8
Action
Hi Pressure Pump Operating slower than Low Pressure Pump
Caused By
GOTO
Hydraulic Imbalance in th...
Page
8
Condition
Design of System
Caused By
STOP
Lack Of Control



Page 5
Condition
Lack of Maintenance Activities
Caused By
Root Cause (C)
No Gland nip ups
Cancelled MST
Caused By
Condition
Lack of Resources
Staffing reductions
Caused By
STOP
Economic Climate
Root Cause (A)
Work order cancelled
Ellipse
Caused By
STOP
Lack Of Control
Action
Poor Packing InstallationTechniques
Pump Training
Caused By
STOP
Cannot be attributted to single person


Page 1
Root Cause (A)
Slurry Abrading Shaft Sleeve surface
Caused By
Action
Packing allowing slurry ingress
Slurry destroying Packing
Caused By
Action
Packing deformed
Flattened out
Caused By
Root Cause (A)
Shaft Deflection
Page 8
Calculations performed
Condition
Packing is Wrong Size
Page 6
Inncorrectly Supplied
Condition
Packing has no elasticity.
Page 12
Standard Packing USed
Condition
Lack of Maintenance Activities
Page 7
Cut back staffing
Condition
Incorrect Installation
Page 13
Twisted Packing could b
Condition
Excessive Clearance
Slurry Exiting
Caused By
GOTO
Shaft Deflection


Page 5
Root Cause (A)
Shaft Deflection
Caused By
Action
Hydraulic Imbalance in thePump
Shaft deflection calcs
Caused By
Condition
Pump operating away from B.E.P
Flow curve
Caused By
STOP
Production requirements - Likely RC
Action
Hi Pressure Pump restricting the Low pressure pump
Schematic
Caused By
Condition
Design of System
?
Page 10
Action
Hi Pressure Pump Operating slower than Low Pressure Pump
?
Page 11
Root Cause (C)
Poor Shaft slenderness ration
L/D
Caused By
Condition
Incorrect Pump application
?
Page 9
Condition
TKL pumps
Warman Gland failures OK
Caused By
STOP
Lack Of Control
Action
Excessive shaft overhang
NDE Bearing Position
Caused By
STOP
Lack Of Control

Appendix H

Letter of Offer concerning Stiffened Shaft Assemblies

KSB Australia Pty Ltd A.C.N. 006 414 642 A.B.N. 29 006 414 642 **KSB Australia Pty Ltd**
Mobile: 0408 202 585 Email brett.lewis@ksbajax.com.au *22th October, 2009*

Rio Tinto Alcan
Gove Operations
Melville Bay Road,
Nhulumbuy NT 0880 Australia
ATTENTION: Damon Bishop
Rotating Equipment Engineer

Dear Sir,

Subject: Mill Injection Pumps
Site: Gove Operations
KSB ref: BL 09-0013

We thank you for your valued enquiry and take the opportunity to offer a quotation for the above and have pleasure in providing our proposal in accordance with KSB Australia Pty Ltd Standard Terms and Conditions of Sale.

1. Introduction

KSB Australia P/L and Georgia Iron Works, or GIW, are both wholly owned subsidiaries of the international KSB AG Group. KSB Australia P/L/ source product as well as manufacture under licence to GIW. The success of our organization is the practiced philosophy in that we strive to build partnerships with our many clients throughout the world, ensuring that productivity is maximized, and in turn generating increasing profits.

2. Executive Summary / Slurry Data

Current gland life of the LSA 6 x 8/25" Mill Injection Pumps is creating production losses. After looking at the slurry data / performance operating conditions, we were able to re-select the pumps and start looking at shaft deflections and gland water pressure etc
The performance and slurry data is follows;

- *Maximum Flow – 366m3/hr*
- *Normal Flow – 340m3/hr*
- *Minimum Flow – 206m3/h*
- *Slurry SG – 1.824 / Solids SG – 2.4 / Liquid Density – 1.3 / Concentration – 54.8%*

The shaft deflection at the three duties is listed below for the standard 3 15/16" shaft which you are using. I have also included the shaft deflection of the 3 15/16" stiffened shaft design and you will note that there is a difference of at least 0.5mm.

Shaft Deflection Table	**366m3/hr - Max**	**340m3/hr - Normal**	**206m3/hr - Min**
LSA 6x8/25 3-15/16" Standard Shaft	0.777mm	0.898mm	0.946mm
LSA 6x8/25 3-5/16" Stiffened Shaft Design	0.277mm	0.290mm	0.292mm

KSB Australia Pty Ltd A.C.N. 006 414 642 A.B.N. 29 006 414 642 **KSB Australia Pty Ltd**
Mobile: 0408 202 585 Email brett.lewis@ksbajax.com.au *Although a shaft deflection of 1mm may be alright in certain applications, it is not a desirable deflection and we would under normal circumstances be looking for a better figure. It may also be worth while checking gland water pressures and flow rates to see if they are as per required. Under "Section: 5.2.3.1 – Stuffing box of the attached LSA-Tech Book", it states the required flush and pressures for gland packing. I have included below a general outlined;*

- *Forward Flush Gland Assembly – 1.3l/s @ 10PSI Above Maximum Discharge Pressure*
- *KE "Low Flow" Gland Assembly – 0.3l/s @ 10PSI Above Maximum Discharge Pressure*

3. Scope of Supply
One (1) LSA 3-15/16" Shaft Bearing Assembly "Stiffened Shaft Design" to suit the original pedestal. Part No – 9283D Assembly.
Price - $27890.00 each nett, excluding GST / Ex works – KSB Tottenham Victoria
Prices quoted are net sell and exclusive of GST. Prices are not subject to rise and fall due to labour and materials if order placed within the Sixty (60) day validity period.

4. Delivery
We would be able to affect delivery of the equipment within 13 working weeks.
Delivery commences after KSB has received the complete technically and commercially clear written order.
Should the above delivery be in conflict with your program, we would be happy to discuss your requirement with our manufacturing group to see if improvement can be made to accommodate your request.

5. Validity
Our proposal is open for acceptance for a period of sixty (60) days then subject to our written confirmation.

6. Payment
100% payable on presentation of invoice thirty (30) days from delivery

7. Warranty

Our equipment is guaranteed for twelve (12) months' operation against any manufacturing failure. This guarantee is limited to eighteen (18) months after shipping of the equipment, the shortest period being retained.

We guarantee that the goods manufactured / supplied by KSB Australia shall be of first class materials and sound workmanship. KSB Australia will make good or replace any defects or defective parts therein, which under proper use may appear.

8. Quality Assurance

KSB Australia Pty Ltd (Australia) has been accredited with Quality Assurance to Australian Standard 3901 and International Standard 9001. Our Quality manual is available for viewing at our Head Office in Melbourne, Victoria.

9. Documentation

One (1) complete set of the following documentation will be supplied after official order has been given to proceed with pump upgrade;

Certified GA Drawing including parts listing
Bill of materials
Operation and maintenance manuals

10. General Comments

Please note that KSB Australia will only comply with customer specifications which have been commented upon. No other specifications or standards even if mentioned in the body of reviewed specifications have been taken into account in this offer.

We trust the above and enclosed meets with your approval and we look forward to discussing your requirements in further detail with you.
We remain at your service.
KSB Australia Pty Ltd
Brett Lewis
Business Development / Technical Support

Appendix I

Power Point Presentation to Management Concerning Mill Injection Shaft Upgrade

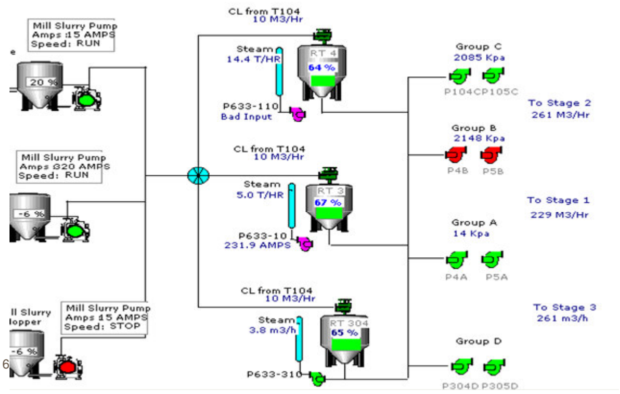
Rio Tinto Alcan

Mill Injection Pumps

Consist of 4 groups. A, B, C and D Group

•A, B and C Group utilise TKL pumps (GIW). These Pumps have been in service since plant commissioning.

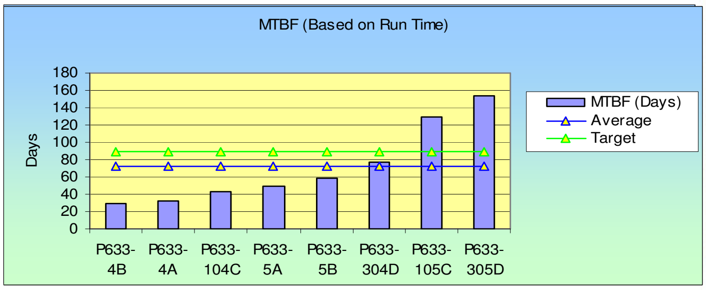
•D Group Pumps were installed as part of G3 and utilise 6/8 Warman pumps.



4

Rio Tinto Alcan

Current Pump Status



•Production Losses due to Gland failure for the Last Year = 1900 Tonnes. (Already 1500 tonnes for this year)

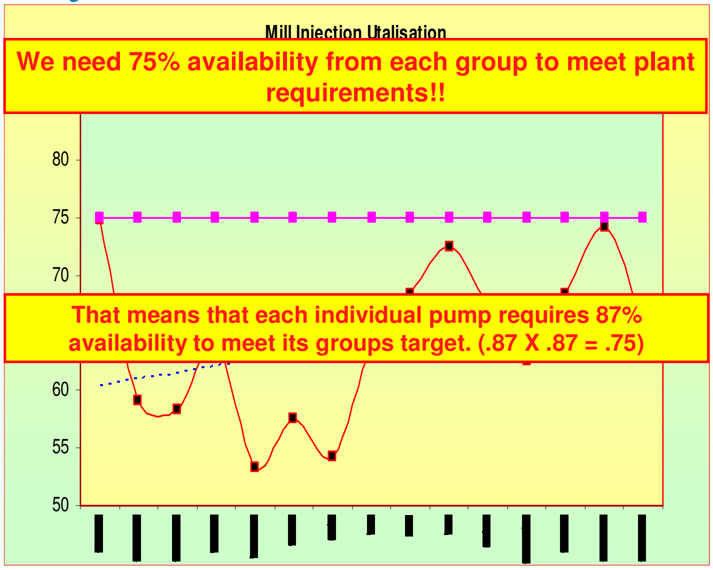
•Highest contributor to Production Losses for Pumps (Second goes to Stage 3 ISC Pumps)

•Second lowest MTBF for Glands (First goes to Pressure Decanter Under Flow Pumps).

•Second largest gland water uses 170 l/min (First goes to Mud Injection in HTD)

6 August 2010 Presentation Title 5

Our current Utilisation of Mill injection



What is the issue? (A, B and C Group)

- We have long suspected Shaft deflection as the root cause and consequently it has limited our ability to improve the gland reliability. Mechanical Seals, Crown Bushes and alternate Packing arrangements have all been trialled with limited or no success.
- This cyclic shaft deflection will
  - deform the packing which will compromises the stuffing boxes ability to seal.
  - Introduce axial loading on Mechanical seals – quickly leading to failure.
  - Cause the shaft sleeve to contact the pump wear plate or flow restrictor bush.
- Discussion with GIW (pump supplier) they offered to quantify the deflection by performing a dynamic analysis of the pumping system.

Rio Tinto Alcan

Calculations Involved

THE BENDING FORCE FORMULA

$$P = \frac{Kq \times K \times H \times S.G. \times D_2 \times B_2}{2.31}$$

P = Pounds of force being generated
K = Radial thrust factor .3 to .35 (see chart A1)
H = Total head @ B.E.P.
S.G. = Specific Gravity of the liquid
B_2 = Width of the impeller including the shrouds(walls)
D_2 = O.D. of the impeller (inches)

$$Kq = 1 - \left(\frac{Q^2}{Qn^2}\right)^2$$

Q = Gallons per minute actually pumping
Q_n = Gpm @ the B.E.P.

METRIC BENDING FORCE FORMULA

$$P = \frac{Kq \times K \times H \times S.G. \times D \times B_2}{10{,}2}$$

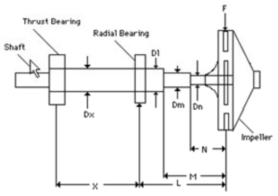
P= Kilograms of force being generated
K= Radial thrust factor 0.3 to 0.35 (See chart A1)
S.G. = Specific Gravity of the liquid
H = Total head @ B.E.P. (meters)
B_2 = Width of the impeller including shrouds(walls) (cm)
D_2 = O.D. of the impeller (cm)

$$Kq = 1 - \left(\frac{Q^2}{Qn^2}\right)^2$$

Q= M^3/hr. actually pumping
Qn= M^3/hr. @ the B.E.P.

CALCULATING SHAFT DEFLECTION

The formula for the full calculation looks like this:



The formula for the calculation of a multi-diameter shaft looks like this:

$$Y = \frac{F}{3E}\left[\frac{L^3-M^3}{I_L}+\frac{M^3-N^3}{I_M}+\frac{N^3}{I_N}+\frac{L^2X}{I_X} - \frac{3X}{2}\left(\frac{L^2-M^2}{I_L}+\frac{M^2-N^2}{I_M}+\frac{N^2}{I_N}+\frac{2LX}{3I_X}\right)+\frac{N^3}{2I_M}\right]$$

- Y = Shaft deflection at the impeller center line measured in inches
- F = Hydraulic Radial imbalance, pounds ("P" in the previous calculation)
- M & N = Distances from the impeller centerline to the steps on the shaft, inches
- L = Distance from impeller centerline to centerline of the inboard bearing, inches
- X = Span between bearing centerlines, inches
- I_L, I_M, I_N, I_X = Moments of inertia of the various diameters, inches
- E = Modulus of elasticity of the shaft material (psi.)

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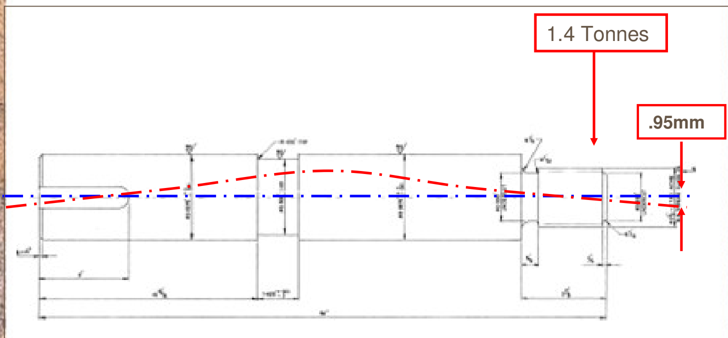
Rio Tinto Alcan

Dynamic analysis results

- Under current pumping conditions the impeller exerts a cyclic radial load of 14122 N on the end of the shaft.
- The consequence of this Radial load is a .95mm deflection in the pumps 104mm Ø shaft.



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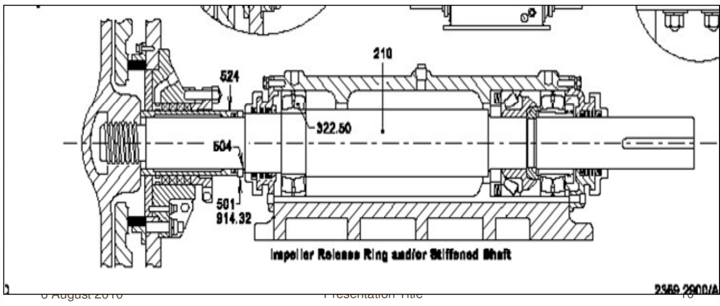
Solution (A, B and C Group)

•Stiffened shaft which will have greater load carrying capacity then the existing shaft due to

- Utilisation of parallel bore bearings instead of tapered adaptor sleeves this will enable larger diameter shaft.
- Increased diameter mid section which will reduce flexing
- Larger diameter sealing journal face
- This will reduce deflection to 0.3mm in worst case scenario.



What's the pain?

- $28,000 per complete Bearing Assembly
- 12 week lead time

Shaft Deflection Table	**366m3/hr - Max**	**340m3/hr - Normal**	**206m3/hr - Min**
LSA 6x8/25 3 - 15/16" Standard Shaft	0.777mm	0.898mm	0.946mm
LSA 6x8/25 3 - 5/16" Stiffened Shaft Design	0.277mm	0.290mm	0.292mm

Appendix J

Capital Project Forms for Mill Injection Shaft Upgrade

Capital Phase Estimate

PROJECT No:	H529	QUOTE ACCURACY (Q):		ENG'G LABOUR RATE ($/hr):		Base Location Factor	1.00	PREPARED BY:	N Manwaring	CHECKED BY:	N Manwaring
TITLE:	Mill Pump Shaft assemblies	ESTIMATE ACCURACY (E):		CON'N LABOUR RATE ($/hr):		Multiplier for Climate	1.10	DATE:	23/03/2010	DATE:	23/03/2010
PHASE:	Implementation	PREVIOUS JOB ACCURACY (P):				Multiplier for Elevation	1.00	REVISION:	A	APPROVED:	

Capital Phase Estimate

DESCRIPTION	RATE	QTY	UNIT	COST / UNIT: COST / UNIT	COST / UNIT: TOTAL MAT'LS	SITE FACTORS: Yes = Y / No = N	LABOUR: TOTAL M/HRS	LABOUR: TOTAL LABOUR	ACCURACY: ACCURACY TYPE (Q / E / P)	ACCURACY: ACCURACY ($)	SUB TOTAL
Management											
No cost										$ -	$ -
										$ -	$ -
										$ -	$ -
										$ -	$ -
										$ -	$ -
											$ -
								$ -			$ -
SUB TOTAL EPCM					$ -		0	$ -		$ -	$ -
Mechanical											
Quotation for pump shaft assenmblies		6	ea	$ 27,890	$ 167,340	N/A		$ -		$ -	$ 167,340
Freight allowance		1	ea	$ 3,000	$ 3,000	N/A		$ -		$ -	$ 3,000
			ea		$ -	N/A		$ -		$ -	$ -
			ea		$ -	N/A		$ -		$ -	$ -
			ea		$ -	N/A		$ -		$ -	$ -
			ea		$ -	N/A		$ -		$ -	$ -
Sub Total Mechanical Construction					$ 170,340		0	$ -		$ -	$ 170,340
Shared Services	RATE										
Estimated scaffolding costs to support pipework contract			ea		$ -	N/A		$ -		$ -	$ -
Sub Total Shared Services					$ -		0	$ -		$ -	$ -
SUB TOTAL CONTRACTOR DISTRIBUTABLES					$ -			$ -		$ -	$ -
Miscellaneous	RATE										
NT Government building levy @ 0.5% of building cost	0.5%		Lot		$ -					-	$ -
Misc & unidentified items (5% of Equipment)	5%		Lot								$ -
Delays & variations, including weather delays (@ 10% of site labour)	10%		Lot								$ -
Accomodation costs construction labour (6% of direct construction lab)	6%		Lot								$ -
											$ -
											$ -
											$ -
											$ -
Rounding up to nearest thousand											$ -
SUB TOTAL MISCELLANEOUS					$ -			$ -		$ -	$ -
Total Capital Phase Costs					$ 170,340		0	$ -		$ -	$ 170,340.0

This is a procurement only project.

Therefore no allowance has been made to use any site construction or supervision resources.

No escalation in vendor pricing is expected greater than 4% hence no additional contingency has been allowed.

This page (p. 101) removed at request of author.
17/8/2012

Request for Authorization

Fields with " * " = mandatory depending on the step

RFA No.	506H529	Title *	Mill Injection Pump Shaft Upgrade	
Status	RFA Phase	Syspro Number	Current Intervening party	1st Year Cost Summary *
Project in Progress	EXE Execution	401-423-605	Nigel Manwaring	2010

Compiler	Damon Bishop/Alcan		
Paying Plant	506 Gove Aluminium Limited	Plant Responsible	506 Gove Aluminium Limited
Paying Organization *	01 Refinery Operations	Org. Responsible *	CPD Capital Projects
Paying Department *	012 Redside - Digestion	Department Responsible *	010 Capital Projects Department
Manager Paying *	Mark Briggs/Alcan	Manager Responsible *	John Waller/Alcan
Promoter (Org. Manager) *	Bob Gordon/Alcan	Manager Org. Responsible *	Scott Savage/Alcan
Promoter Representative *	Mark Briggs/Alcan	User Representative *	Mark Briggs/Alcan
Plant Priority	1 Critical project (within 12 months)	Organization Priority	1 Urgent
Program	Digestion	Program Responsible	Nigel Manwaring/Alcan
Project manager	Nigel Manwaring/Alcan		

	Total RFA Amount			Project forecast	
In thousands (,000)	Fixed capital	Expense	US $ equivalent amount	Fixed capital	Expense
	170.3 K AUD	0.0 K AUD	Required if the RFA's amount is greater than the plant limit	170.3 K AUD	0.0 K AUD
Total	170.3 K AUD		K USD		170.3 K AUD

Offensive / Defensive *	Non Routine	RFA type *	Sustaining
Project Type *	Sustaining		
Target start date *	Mar 31, 2010	Target completion date *	Oct 29, 2010
Actual start date	Apr 6, 2010	Actual completion date	

Project nature (What) *

This project will upgrade the shafts of the mill injection pumps (A, B and C group) with stiffer shafts.

This stiffer shaft will reduce the current shaft deflection from 1mm to .3mm (refer KSB pumps letter of offer).

This will have benefits of reducing production losses, maintenance costs and gland water reduction.

This RFA requests execution funds for purchase of only.

Installation costs have been agreed to be covered by site maintenance because the shafts are expected to be changed out within a 3 month period during normal maintenance activities.

Refer Idea definition form for more detail.

Justifications (Why) *

Refer Idea definition form for more detail.

Why now *

Refer Idea definition form for more detail.

Alternatives *

Alt 1
Replace the make of pump with a Warman pump. Warman pumps traditionally have a lower shaft slenderness ratio which results in increased gland reliability. This however would cost 4 to 10 times more than the current proposed solution.

Alt 2
Buy the shafts at $8000 each (x6) and perform our own upgrades with our facilities onsite with risk of possible shaft failures and design refinement period.

Refer Idea definition form for more detail.

Summary of risks * .

Contingency * .

Comments * .

Attachments

Idea Initiation Form

H529-03-01 Mill injection pump shaft upgrade I(

CEA

H529 CEA.pdf.zip

Capital Estimate

H529 Cap Est.pdf.zip

Chart Of Accounts

H529PROC - Procurement - $170,340

NPV

H529-04-03 NPV.xls.zip

KSB Pumps Letter of Offer

KSB Quotation.pdf.zip

	GHG	SO_2
Impact on emissions	tons	tons
Complies with Alcan/local commitements		
Constraints		
Energy	N/A	Quant. measures (kw,cm,cfm,psi,etc)
Services	N/A	Quant. m,psi,etc)

Considerations (check list only - details covered in evaluation below)

Attachments

Health & safety *	N/A
Environment *	N/A
Maintenance LCC *	N/A
Key Equipment	No