University of Southern Queensland
Faculty of Engineering and Surveying

ROLLING STOCK BEARING CONDITION MONITORING SYSTEMS

A dissertation submitted by

Alfio Concetto Lamari

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ENG4111 and ENG4112 Research Project

towards the degree of

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Abstract

The Australian sugar industry has evolved dramatically throughout its long history, having overcome numerous obstacles through the adoption and development of new systems and techniques. CSR Sugar has been at the forefront of research and development into all aspects related to the sugar industry. The transportation of sugar cane, from the surrounding fields, to the sugar mills for processing is a very important facet to the production of raw sugar. However, problems associated with product transportation require constant innovative approaches and solutions, in an attempt to minimise impacts to safety, environment and health, whilst maximising equipment reliability.

The purpose of this dissertation is to review the current CSR Sugar rolling stock bearing condition monitoring systems and to research the suitability of other systems and techniques to improve the current preventative maintenance programs.

The current wheel bearing condition monitoring methods used by CSR will be investigated to determine their potential weaknesses and identify areas which would benefit through implemented improvements. Information collated through researching industries that utilise rail systems and other specific technologies, will provide possible alternatives to current CSR systems requirements. Conducting a generalised cost analysis on particular adaptations and or improvements of equipment will illustrate the options available based on a financial perspective.

This investigation seeks to identify problems that currently affect the safety, health, reliability and maintenance costs associated with sugar cane wagons. The benefits of utilising the investigative results will assist in facilitating improvements through the implementation of suitable, financially viable alternatives; hence increasing revenue and therefore providing the Australian sugar industry with a more positive future.

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Alfio Concetto Lamari

Student Number: 0038970158

Signature

Monday, 20th October 2008

Date

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Table of Contents

List of Figures

List of Tables

List of Appendices

Chapter 1: Project Introduction.

1.1 Introduction

The Queensland sugar industry extensively utilises narrow gauge railway systems for the transportation of sugar cane and processed raw sugar.

The equipment that travels on these narrow gauge railways is termed rolling stock. It includes diesel locomotives, cane bins (wagons), brake vans that aid locomotives to decrease the speed of the rake of cane bins and in various sugar producing areas, raw sugar wagons, which are used to transport the raw sugar product to sugar loading facilities at various ports.

This project focuses on the cane bins and in particular their axle bearings. Research was undertaken to evaluate the current bearing condition monitoring systems within the industry and related industries to facilitate an improvement in safety, reliability and to reduce maintenance costs associated with sugar cane bins.

1.2 Project Aim

To review the current CSR Sugar rolling stock bearing condition monitoring systems and to research the suitability of other systems and techniques, with a view to improve current preventative maintenance programs.

1.3 Project Objectives

1. To undertake a literature review of rolling stock bearing condition monitoring techniques and systems.

   This will give an appreciation of any research conducted within the industry and other related industries with regards to this project topic.

2. Define and describe current systems of bearing condition monitoring and benchmark systems within the industry and other industries with similar equipment.

   An understanding and description of the current systems will demonstrate the complexity of the problem at hand.

3. Identify significant problems with current systems of bearing monitoring and failure prediction.

   Information gathered will be utilised to identify possible significant flaws within the current system with a view to providing recommendations towards the improvement of such systems through the minimisation and rectification of said problems.

4. Propose solutions to the identified problems by discussing alternative techniques and their suitability to the application.

   Clear informed recommendations will be made once all the information has been collated. This will show the best possible systems and outcomes that may be achieved.

5. Conduct a cost benefit analysis of the suggested solutions.

   This will ensure the best possible outcomes in terms of financial outlay for the business.

6. Write a dissertation of the project, work which includes a report of the findings to the sponsored company.

7. If time permits, report on any implemented solutions.

1.4 Overview of the Dissertation

As the basic objective for this project is to improve the safety and reliability of the current cane bin fleet, through an improved preventative maintenance program, the first step in this research project is to fully comprehend the task at hand. Discussions will be undertaken with professional individuals within the sugar industry (CSR Sugar) as well as site visits to local sugar mills, to gain an appreciation of the problematic nature of current systems. Throughout these site visits attention will be given to the systems and techniques currently implemented to monitor the cane bin bearings. It is also to be noted that whilst it is impractical for all CSR Sugar sites involved in this project to be physically examined, local knowledge and information regarding these sites will be gathered through discussions conducted with relevant professionals and utilised for the purpose of this project.

When the current systems have been reviewed and problems identified, other industry systems that depend on similar technology will be researched to ascertain their adaptability, suitability and feasibility to perform the task of condition monitoring of cane bin axle bearings. Literature, in conjunction with discussions undertaken with professionals within their respective industries, will provide a review that will encompass global rail industries' monitoring systems, as well as technology and techniques, which to date, have not been adopted within the sugar industry for the purpose of rolling stock condition monitoring.

This dissertation will follow the chapter structure as follows:

Chapter 2 Provides the historical and background knowledge of the narrow gauge railway usage in the sugar industry and the cane bins that run along on them, with a focus on the axle wheel bearings. A literature review on condition monitoring of rolling stock bearings will follow.

Chapter 3 Describes the current methods and systems of cane bin axle bearing condition monitoring and their short falls.

Chapter 4 Research into other systems used in similar industries and their ability to be applied to the sugar industry.

Chapter 5 Recommendations and a cost analysis performed.

Chapter 6 Conclusions to the dissertation are made and recommendations of further work noted.

1.5 Conclusion

The need for an improved bearing condition monitoring system on rolling stock bearings is required for the Australian sugar industry to stay at the forefront of innovations and to remain competitive in the world market. The following chapter gives some background knowledge of the Australian sugar industry and the cane bins at the centre of this project, to appreciate the required application of a condition monitoring system.

Chapter 2: Background and Literature Review.

2.1 Introduction

The introduction of sugar cane to Australia dates back to the first fleet. By 1867 the industry had expanded sufficiently to require a means of reliable and efficient transportation of the product. The first known use of narrow gauge railway for cane transportation is 1866, by George Raff of Morayfield, north of Brisbane (Light Railway Research Society of Australia. Inc. website 2008). Initially used on a sugar plantation located in the Brisbane surrounds, the rail provided the means to transport the sugar cane to the nearby mill and the raw sugar product to the Brisbane Wharf.

A number of other estates were quick to realise the benefits of the narrow gauge rail (tramway) by the 1880s, with most wagons being hauled by horse, whilst a minority were dependent on the newly introduced steam locomotive to the industry.

As stated in the Light Railway Research Society of Australia Inc. website (2008), the Colonial Sugar Refining Company, the forerunner to the modern day CSR Sugar, was established in 1855. By 1875 they were utilising a 610mm gauge tramway to transport sugar cane from the surrounding plantations in northern New South Wales to nearby rivers, in preparation for loading on river barges for transportation to the mills further down stream.

CSR Sugar went on to use this rail gauge system in all of their sugar mills, with the exception of one. Within a selected number of rural communities these tramways were also utilised for the transportation of paying passengers. CSR Sugar presently utilises approximately 860km of main line tramway and a total of 1300km of tramway, including sidings and yards remains in use, transporting an average of 14.2 million tonnes of sugar cane annually to its seven mills in three districts along the Queensland coastline.

2.2 Modern Day Sugar Cane Rolling Stock

The reliability and serviceability of the wheel bearings on the wagons, now identified as cane bins, are of great importance to millers and farmers alike, as the cane bins' continued use is required to transport the crop safely and efficiently. Problems, such as derailments, caused through bearing failures may include personal safety issues to operators and members of the general public, as well as tramway damage, loss of product and processing delays to the sugar mills. The ability to effectively monitor the condition of these bearings and perhaps predict failures, hence eliminating or minimizing derailments, is of great importance and is the purpose of this research. Figure 2.1 illustrates an example of a CSR Sugar cane train and cane bins. This is indicative of the equipment used throughout the North Queensland sugar industry.

The modern day rolling stock and cane bins, which travel on these tramways, are a fundamental link in the transportation of sugar cane from the surrounding fields to the mills. Figures 2.2, 2.3 and 2.4 are examples of 4, 6 and 11 tonne cane bins, respectively. There are also 4.7 and 5 tonne cane bins in use, with a total of approximately 20000 cane bins, 470 of which are the larger 11 tonne units with four axles. This equates to over 81000 bearings in total to be monitored.

Figure 2.1 Sugar cane trains. (CSR Sugar)

Figure 2.2 Four tonne cane bin. (CSR Sugar)

Figure 2.3 Six tonne cane bin. (CSR Sugar)

Figure 2.4 Eleven tonne cane bin. (CSR Sugar)

The axle wheel bearings are an integral and significant component of the cane bin and whilst the bearings are presently not the major cause of derailments within the industry, they still remain a significant contributor to derailments. Figure 2.5 is indicative of the 2004-2005 figures pertaining to yearly derailments within the CSR fleet and it can be seen that aside from operator error, there is a significant increase in cane bin failures.

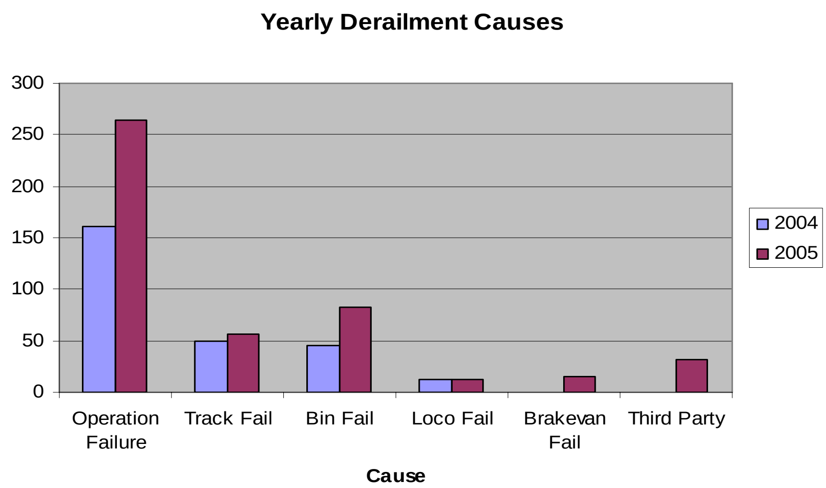


Figure 2.5 Yearly derailment causes. (CSR Sugar)

As an indication of the rising bearing failure rates, figure 2.6 shows the alarming trend a one sugar mill that has contributed to the rising bin failures in figure 2.5. An example of a typical wheel set is given in figures 2.7.and 2.8.

It is to be noted that the information in figure 2.6 was taken prior to the information of figure 2.5, however the trends are consistent.

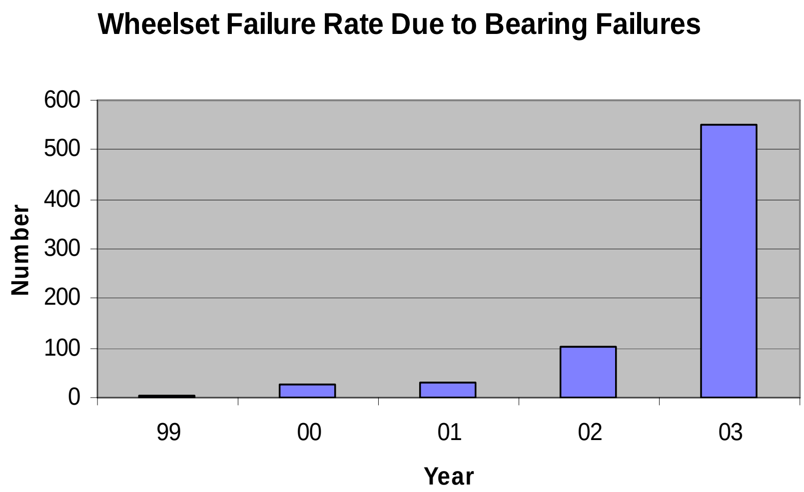


Figure 2.6 Wheel set failure rate due to bearing failures. (CSR Sugar)

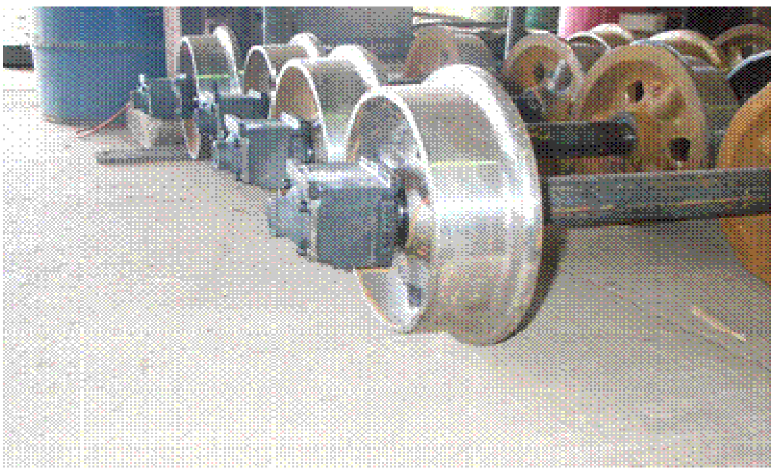
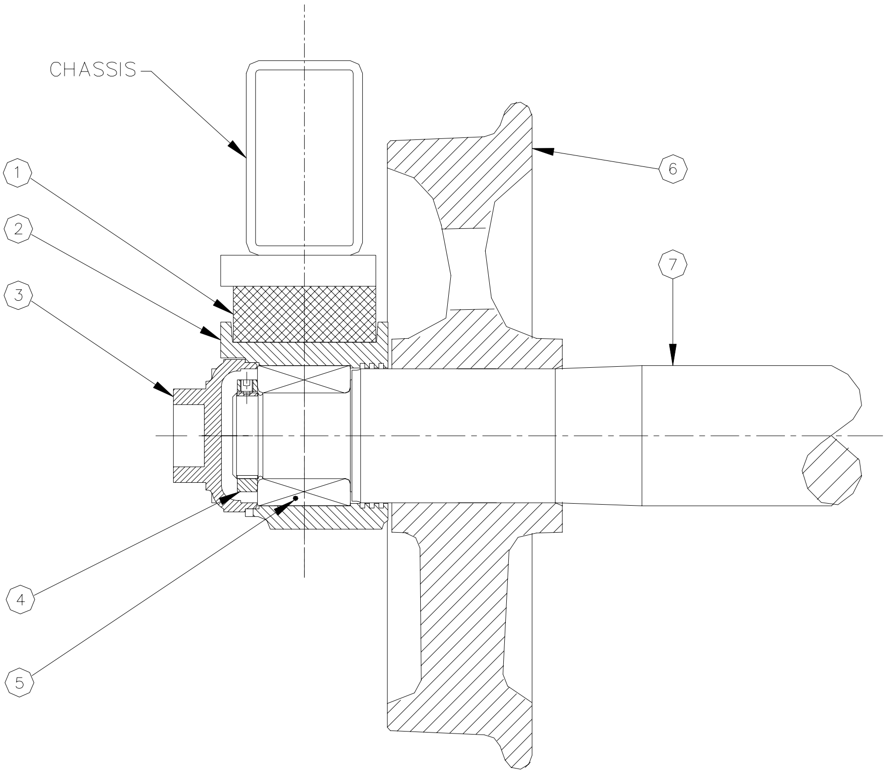


Figure 2.7 Typical wheel set. (CSR Sugar)



7	1	Ø90 mm AXLE	–
6	2	WHEEL (Q062)	CAST STEEL
5	2	SKF BTH-1011 AB BEARING	–
4	2	SKF KMK 11 LOCK NUT	–
3	2	AXLE BOX END CAP	GREY C.I.
2	2	AXLE BOX HOUSING	GREY C.I.
1	2	2 STAGE SUPENSION BLOCK (124x80x36)	RUBBER
ITEM	QTY.	DESCRIPTION	MATL.

Figure 2.8 Typical wheel set components.

The seasonal nature of the sugar industry in Queensland requires that the cane bins be in continual 24-hour operation for approximately half of the year. On average the harvesting, or “crushing season”, length is approximately 25 weeks; however it is dependent on the crop size to be harvested within each district. For the remainder of the year, the cane bins are repaired and then stand idle in preparation for the next season. This idle time contributes to bearing failures and will be discussed later in the dissertation.

As Santarossa, LG and Camuglia JJ (2005) stated in 2003, many types of bearings have been used in the development of cane bins to meet the changing industry requirements. The cane bin has evolved from a timber-framed construction with a bronze bush plain bearing to the modern day steel framed and rolling element bearing cane bin. Types of rolling element bearings have also changed during this evolution period. The driving factors contributing to this have been the escalation of maintenance costs, the availability of bearing components, the suitability of bearings to a particular environment and an increase in axle loading, due to an expanding industry.

The increase in axle loading is resultant from improved cane bin designs, which endeavour to maximise capacities and productivity. Figure 2.9, taken from CSR Sugar's cane bin records, indicates a distinct increase in axle loading in relation to the changing and expanding industry.

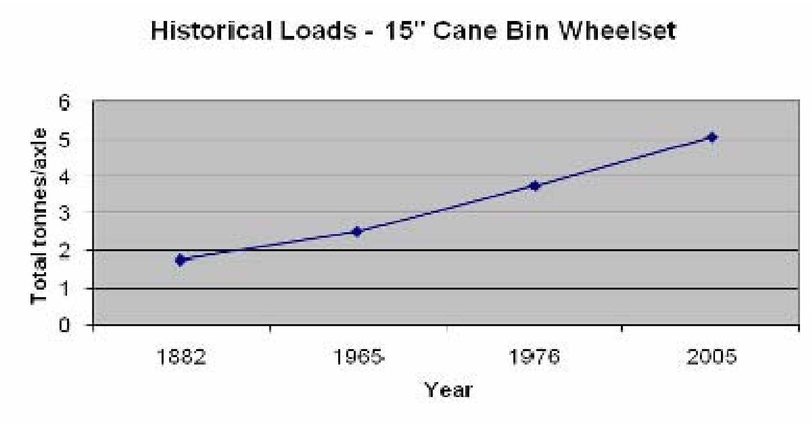


Figure 2.9 Historical axle loads. (CSR Sugar)

The dynamics and the ever evolving nature of the industry have prompted the changes in bearing types and sealing arrangements. CSR Sugar has chosen to utilise various bearing configurations to accommodate the service demands within the industry.

Circa 1955, the introduction of rolling element bearing types into the cane bin fleets first appeared. The development and improvement of cane bin designs simultaneously resulted in the necessity for the improvement of bearing design functionality. This period of evolution saw the introduction of bearings such as the double row ball configurations (SKF 2309), which were then replaced by the double row spherical roller design (SKF 22309) and in recent years, substituted with the tapered roller bearings (SKF 331983/Q). Whilst the majority of the cane bin fleet are presently outfitted with the latest bearing types, there still remains a minority of the fleet that are in service that are functioning with the SKF 22309 bearings. Consideration has also been made to the use of a sealed bearing unit, known as a truck bearing, with designation SKF BTH-1011 AB. This bearing is similar in type to the SKF 331983/Q bearing, in that they are both tapered roller bearings, however the truck bearing does not need periodic greasing, due to its sealed configuration, resulting in less service costs. Trials with this bearing have shown promise. The figure 2.10 illustrates a sample of the currently used SKF 331983/Q bearing.

Figure 2.10 Currently utilised bearing.

2.3 Bearing Selection

Bearing selection is a major contributing factor in cane bin designs, with the objective being optimum performance with minimal procurement and ongoing maintenance costs. Therefore, much consideration is given to the correct bearing selection.

General basic points to note when selecting a bearing are,

- Loads to be considered.
- The speed at which the bearing will operate.
- Any misalignment the bearing may encounter.
- The presence of axial displacement during normal operation.
- The types of seals, if any required.
- The accuracy requirements of the bearing.
- The physical dimensions of the bearing for the application.
- The ability to be serviced / replaced easily in the application.
- The in service environment of the bearing.
- Lubrication requirements.

There are many other aspects to consider whilst selection is being undertaken. The general selection criteria for cane bin axle bearings are given above and the list gives an appreciation of the factors that require consideration. Figure 2.11 gives an overview of how one can best select the correct bearing in a general situation.

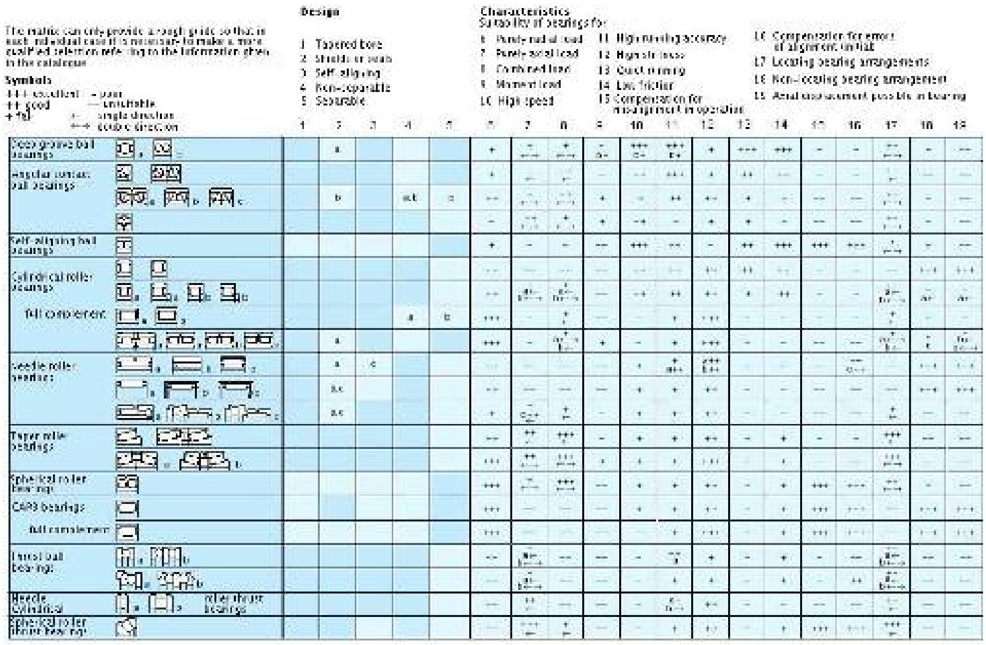


Figure 2.1 SKF bearing selection matrix. (SKF website, 2008)

2.4 Lubrication Theory

One of the functional aspects for consideration regarding cane bin bearings, as with the majority of all rolling element bearings, is the lubrication requirements to achieve the maximum service life. Many bearing manufacturers give lubrication recommendations that are best suited to the application.

The basic functions that lubrication performs in rolling element bearings is to inhibit bearing component wear, through the elimination of metal to metal contact, corrosion prevention and dissipation of generated heat. These functions support and maintain general bearing health and longevity. However, the use of an incorrect lubricant may have adverse effects on the machinery to which it has been applied; for example, a sliding motion of the bearing components, rather than rolling.

Whilst lubrication performs the above functions, it is necessary to choose the correct type, frequency and form of lubricant for the application. Hence, factors such as bearing speeds and temperatures and environment conditions are to be considered when selecting lubricants and correct seals types for a particular service requirement.

In recent years CSR has reduced costs associated with cane bin greasing by increasing the intervals between applications. This was achieved after improving the lubricant and the installation of superior seals.

Various forms of lubricants are available on the market; however the most commonly used by CSR are the mineral based greases.

2.5 Mechanics of Bearing Operation

The primary function of a rolling element bearing is to reduce friction, hence increasing efficiency and component life. As mentioned previously, it is imperative that cane bins experience ease of movement on rail tracks, hence correct bearing choice is mandatory if this is to be maintained. The specific criterion discussed in section 2.3, encompasses several types of loads that the bearings may encounter whilst in operation.

The bearings of interest in this project are subjected to four main loads. Generally the bearing would only be required to support the weight (radial forces) of a loaded cane bin and overcome frictional forces. However, whilst in operation, the bearing will encounter additional forces such as, misalignment and axial forces. A representation of these wheel set forces are illustrated in figure 2.12, whilst figure 2.13 illustrates the main forces of interest. All forces, with the exception of frictional, can be classified as shock loading forces due to the geometry of the rail track and the cane bin.

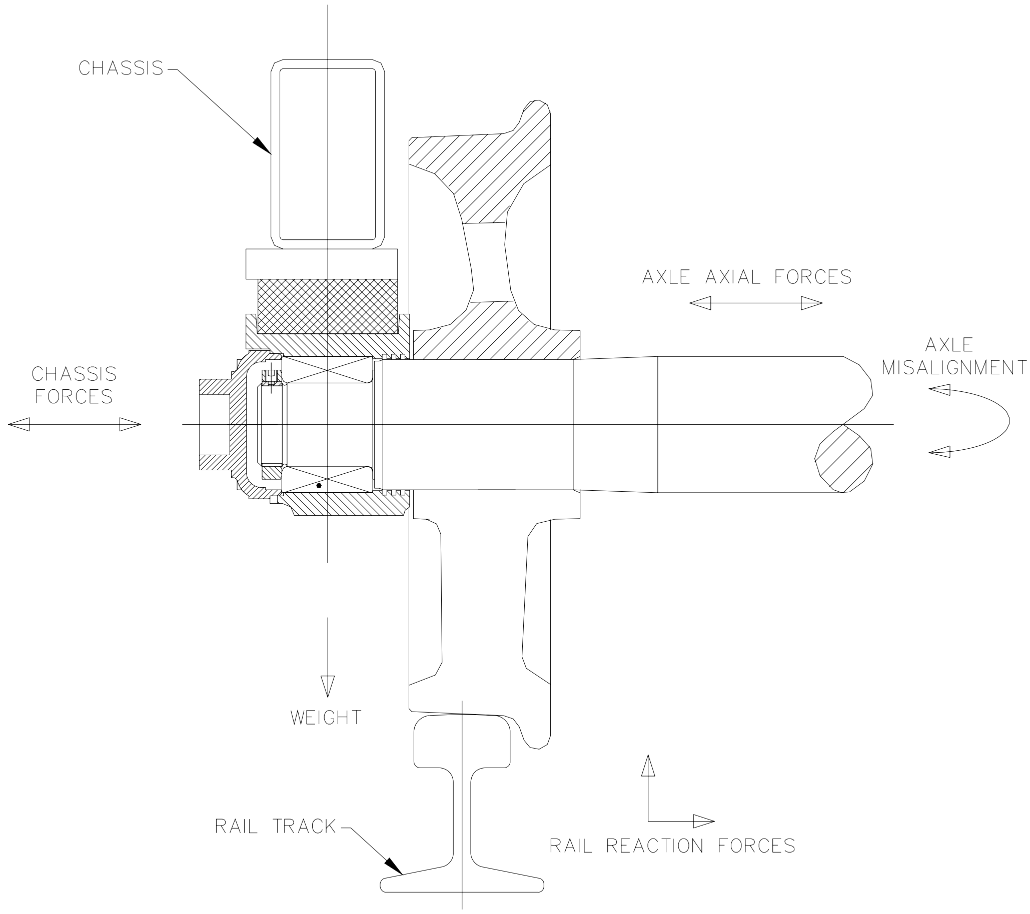


Figure 2.12 Wheel set forces.

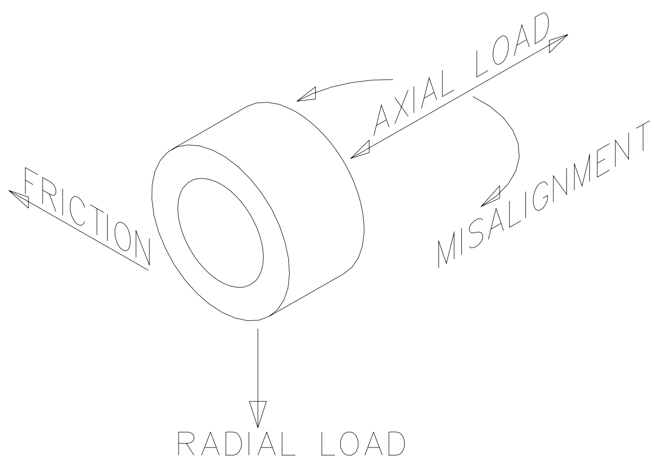


Figure 2.13 Forces acting on a cane bin bearing.

2.6 Bearing Life Calculation

Many factors influence the serviceable life of a rolling element bearing. Of the forces shown in figures 2.12 and 2.13, the major contributing forces affecting bearing life is the radial and the rail track forces. For the purpose of this calculation, all forces, except the radial force, have been neglected, as it is of the greatest magnitude and will be used to calculate the basic bearing life of a currently utilised SKF 331983/Q bearing on a four tonne cane bin.

Factors to be considered in the calculation are the basic dynamic load rating of the bearing, the static axle load, the mass of the axle, the wheel diameter and other factors, such as track conditions. It is to be noted that a four tonne cane bin has a tare weight of one tonne and a gross mass of five tonnes when loaded.

For the four tonne cane bin and bearing in question, the following applies:

C = Basic dynamic load rating, (N).

G_{SA} = Static axle load, (kg).

G_{UN} = Unsprung mass of axle, (kg).

D_w = Wheel diameter, (m).

F_L = Radial load factor (track conditions).

G = Static bearing load, (N).

P = Equivalent bearing load, (N).

Information on the 331983/Q bearing is difficult to obtain as it is not listed in the general product catalogue, as it is unique to the sugar industry. Information for the bearing was accessed through CSR Sugar, along with the cane bin information and is as follows:

$C = 135000$ N

$G_{SA} = 2500$ kg

$G_{UN} = 156$ kg

$D_w = 0.381$ m

$F_L = 1.3$

The static bearing load is calculated as follows:

$$G = 0.5\ (G_{SA} - G_{UN}) \qquad (2.1)$$

$$= 0.5 \times (2500 - 156) \times 10$$

$$= 11720 \text{ N}$$

The equivalent bearing load is calculated as follows:

$$P = F_L \times G \qquad (2.2)$$

$$= 1.3 \times 11720$$

$$= 15236 \text{ N}$$

The basic rating life, or L_{10} life, can be calculated in millions of revolutions. Section 7.3.1 of the Australian Standard, AS 2729 (Standards Association of Australia 1994) states the formula for the calculation of bearing life of a radial roller bearing life and is as follows:

$$L_{10} = \left(\frac{C}{P}\right)^{\frac{10}{3}} \qquad (2.3)$$

$$= \left(\frac{135000}{15236}\right)^{\frac{10}{3}}$$

$$= 1439.50$$

≈ 1440 million revolutions.

The basic bearing life can be represented as a distance travelled or a time period of continuous service. The maximum distance, D_m, in millions of kilometres that corresponds to the L_{10} life is calculated as follows:

$$D_m = \left(\frac{\left(\frac{L_{10}}{\pi \times D_W} \right)}{1000} \right) \quad (2.4)$$

$$= \left(\frac{\left(\frac{1440}{\pi \times 0.381} \right)}{1000} \right)$$

$$= 1.2 \text{ million km}$$

Assuming the average speed of the cane train is 20 km/h, the time of continuous bearing service T, is calculated as follows:

$$T = D_m \text{ x average speed} \quad (2.5)$$

$$= 1\ 200\ 000 \text{ x } 20$$

$$= 24 \text{ million hours}$$

Assuming the cane bin travels 240 km per day for 25 weeks, the time in years that corresponds to this, is calculated as follows:

$$TIME(years) = \frac{1200000}{25 \times 7 \times 240} \quad (2.6)$$

$$= 28.57 \text{ years}$$

This bearing life and distance calculation above assumes the cane bin is loaded continuously through out the life of the bearing. In reality, the cane bins will travel only half that distance fully loaded, whilst returning to the sugar mill. This information would suggest that the bearing service life would increase in relation to the above calculations. However, many bearings have failed prematurely due to the many factors that will be discussed in the following section.

2.7 Bearing Failure Analysis

Extensive discussions have been conducted to establish the cause of bearing failures in cane bins. Many factors contribute to these failures, some of which occur individually or in conjunction with others, resulting in detrimental bearing failure.

Some of the general factors that pose problems include cessation of bearing service life, incorrect bearing selection in terms of functionality or load carrying capacity, inherent bearing defects due to manufacture or installation, un-replenished aged lubricants and lack or incorrect use of lubrication.

Industry specific factors include particle contamination in the grease lubricant, due to wear from components, such as seals and axle boxes, condensation, environmental factors such as water and mud sediment from flooding during idle periods, poor or damaged seals which allow dust and other foreign bodies entry into the lubricant and grease deterioration during sedentary periods, which leads to oil separating from the lubricant structure.

Other factors directly responsible for bearing failure, but not specifically bearing orientated, include rail conditions that may increase axle load distribution, out of balance forces due to poor wheel castings and bent axles from previous derailments and or mill bin feeding equipment.

Whilst there are several common types of bearing faults, the four most commonly found are the hot bearing, which occurs when a bearing becomes abnormally heated through overloading and or lack of lubrication, spalling, due to abnormally high stresses and or overloading, fretting, due to extensive vibration and spun cone, which occurs when component tolerances diminish causing bearing mountings to loosen. Figure 2.14 illustrates an example of a failed bearing.

Figure 2.14 Failed bearing. (CSR Sugar)

2.8 Condition Monitoring Overview

Condition monitoring is one aspect of a predictive maintenance program. The information collected can be used to establish problems associated with equipment and corrective actions can then be implemented.

The manner in which one measures the condition of bearings that have not failed is of interest and is a major component of this dissertation.

Generally, the consensus is that there are four main indicators to determine bearing condition; oil or particle analysis, temperature, mechanical vibration and acoustic vibration. The latter is a recent concept that has generated a considerable amount of interest in recent years within the rail industry.

With consideration given only to rolling element bearings, the above fault indicators can be of great value, as well as a hindrance, as many incorrect readings result in unwarranted alarms. Oil analysis can give an indication of microscopic wear particles present in the lubricant, which can be deemed as bearing wear and analyses can periodically be performed to trend bearing conditions. Regrettably, the distinction between bearings and other related components are sometimes difficult to differentiate between, as materials can occasionally be similar in integrity.

A temperature rise in a bearing can be indicative of possible failure, lack of lubrication and overloading, factors that can dramatically reduce bearing life. Unfortunately, ambient temperature and minimal internal radial clearances, associated to new bearings, can have an effect on bearing temperature, resulting in instances that would initiate alarm. The elevated temperatures in cane bin bearings can be associated to bearing wear, bent axles, chassis alignment problems, which can create flanging, that is, incorrect wheel/track contact, axle box wear and loose seal carrier and bearings.

Vibration and acoustic monitoring methods are inherently more reliable, as they analyse bearing components. Wear (looseness), outer and inner bearing race, ball and cage defects can all be determined by vibration and acoustic monitoring systems, as a unique vibration and or acoustic signature is captured, processed and analysed, allowing identification of potential defects and problems.

Presently the sugar industry does not utilise vibration and acoustic monitoring techniques, however they (CSR Sugar) are open to investigating the suitability of alternative monitoring systems for implementation into their rolling stock fleet management and maintenance.

The use of an effective bearing condition monitoring system, where the data obtained can be used to make informed decisions, can be an invaluable tool in maintaining of an effective cane bin fleet.

2.8.1 Vibration Analysis

One of the many forms of condition monitoring utilises the principles of vibration analysis. This system has been successfully utilised for many years to examine various types of machinery through the monitoring of equipment as a whole, measuring the vibration of the overall machine or through the analysis of the individual components. Essentially, the method measuring the vibration of individual components in many cases is the most effective method of monitoring the condition of rolling element bearings. However, machinery with few components can effectively be monitored using the overall method.

These vibrations are utilised to trend machinery and components, tracking any changes that may arise. These changes indicate that there maybe problems associated with the machinery and that further monitoring is required until such time as maintenance can be undertaken.

Vibration can be defined as the motion of a machine and its components from a rest position. This motion is due to external forces acting to produce motion or movement inherent to that particular machine, its components and use. This measurement can be ascertained through the use of specific equipment consisting of an accelerometer, which converts the vibrating motion to an electrical signal in preparation for analysis. Initially, this method is utilised to trend the specific machine's and components' integrity at a point of optimum performance and reliability. This motion is directly associated to a sinusoidal wave form, having characteristics of frequency, amplitude, wavelength and phase. Once a measurement of machine vibration has been obtained, several sinusoidal waveforms or motions are usually present and combine to give an overall time wave form. To improve the use of this wave form, a Fourier analysis is performed using specialised equipment to convert the time wave form to an amplitude verses frequency spectrum. This equipment is known as a Fourier transform analyser or a Fast Fourier Transform (FFT).

The frequency spectrum identifies the frequency which gives an indication of possible components that may have problems. This frequency forms an essential part of the analysis in conjunction with the amplitude. The amplitude identifies the magnitude of the component vibration, giving an indication of its condition. It is to be noted that time wave form analysis is also very useful, as it identifies discrepancies and energy developed by vibrations.

Taylor (1994, pg. 84) "Both time signal and frequency spectra must be analysed to identify a problem"

The vibration amplitudes are measured in parameters of displacement, velocity and acceleration. The choice on which one to use is dependant on the frequency. Low frequencies, usually between 0-10 Hz utilise displacement as the unit of choice, whilst velocity would be chosen to analyses a frequency between 10-100 Hz and acceleration for frequencies between greater than 1000 Hz.

Vibration analysis can be used on a multitude of equipment. It can detect defects in the gear components of power transmission units, electric motor components, fans, pumps as well as all bearings associated with this equipment. Vibration analysis can also test for misalignments, imbalances that may be associated with bent shafts and looseness associated with machine components.

When dealing with rolling element bearing vibration, it is imperative that the bearing internal geometry is a known, to distinguish the frequencies that are generated by the bearing elements. Rolling element bearing components include outer and inner races and a containment cage that hold either balls or rollers as described in figure 2.15.

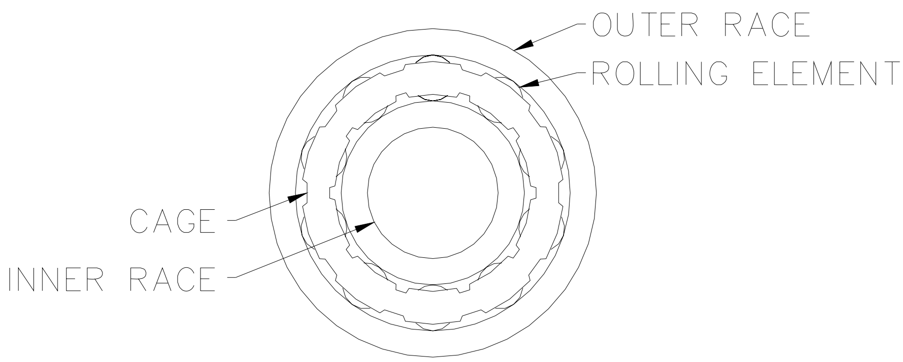


Figure 2.15 Basic bearing geometry.

Each of the rolling element bearing components develops unique frequencies when in operation. The frequencies developed are calculated for individual bearings by utilising formulas (Taylor & Kirkland 2004, p. 26) where:

B = Ball/roller diameter

N = Number of rolling elements

P = Pitch diameter of the bearing

S = Rotational speed of the bearing

Φ = Bearing contact angle

The calculation for the outer race is known as Ball Pass Frequency Outer Race (BPFO) and is as follows:

$$BPFO = S\frac{N}{2}\left(1 - \frac{B\cos\Phi}{P}\right) \quad (2.7)$$

The calculation for the inner race is known as Ball Pass Frequency Inner Race (BPFI) and is as follows:

$$BPFI = S\frac{N}{2}\left(1 + \frac{B\cos\Phi}{P}\right) \quad (2.8)$$

The calculation for the Ball Speed Frequency (BSF) is as follows:

$$BSF = S\frac{P}{2B}\left(1 - \frac{B^2\cos^2\Phi}{P^2}\right) \quad (2.9)$$

The calculation for the Fundamental Train Frequency (FTF_I), (Cage spin frequency when the inner race of the bearing is the rotating component) is as follows:

$$FTF_I = \frac{S}{2}\left(1 - \frac{B\cos\Phi}{P}\right) \quad (2.10)$$

The calculation for the Fundamental Train Frequency (FTF_O), (Cage spin frequency when the outer race of the bearing is the rotating component) is as follows:

$$FTF_O = \frac{S}{2}\left(1 + \frac{B\cos\Phi}{P}\right) \quad (2.11)$$

Whilst the above equations are utilised in ascertaining individual frequencies, they are only a small section that contributes to the overall theory required for comprehensive vibration analysis of rolling element bearings. Although an extensive discussion in relation to vibration analysis will not be undertaken, the concept of vibration analysis will be discussed in later chapters. Figures 2.16 and 2.17 illustrate an example of a time signal and frequency spectra of a bearing in an operating pump application.

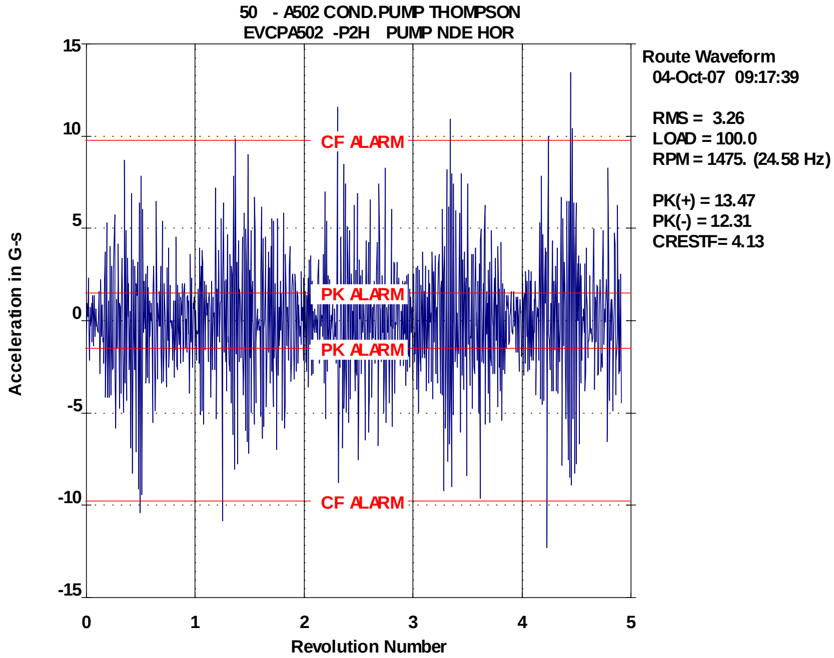


Figure 2.16 Time signal spectra. (CSR Sugar)

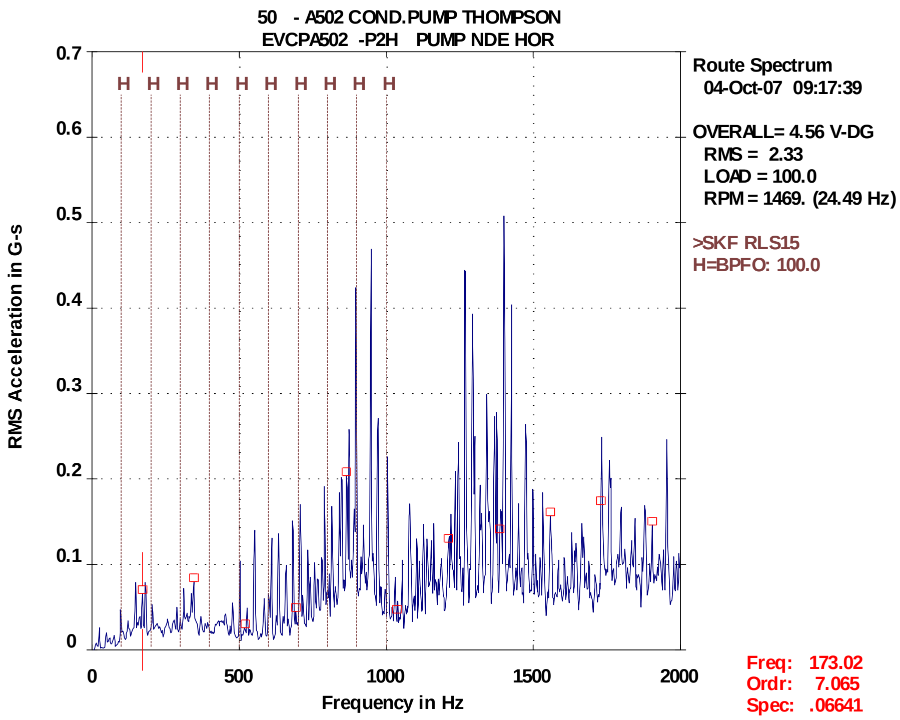


Figure 2.17 Frequency spectra. (CSR Sugar)

2.8.2 Acoustic Monitoring

Similar in many aspects to vibration monitoring, where a physical vibration is measured; acoustic monitoring involves the measurement of the audio signature emitted by components. The audio signature is derived from the impact frequencies associated with bearing defects. The concept behind acoustic monitoring is to capture these impact frequencies as they occur. Utilising specialised equipment, the microphones capturing the audio signals send relevant data to computers, where these signals are then processed and differentiated using specifically designed software.

As with vibration analysis, the type of bearing, manufacturer and the operating speed of the bearing must be known factors, so as to obtain consistent results.

2.8.3 Thermography and Infra-red Technology

One of the many forms of conditioning monitoring of machine components is to measure heat emitted from operating equipment. Thermal energy is distinguished by heat that is passing from a high temperature to a low temperature, hence altering the energy levels of the objects.

Heat is transferred in three different manners, conduction, convection and radiation. The first, conduction, is associated with solid objects, where the heat is transferred through the molecular structure of the entity. The second manner, convection, is the transfer of heat from a usually stationary object to a fluid passing over a heated surface. Convection occurs by either a natural or forced process, with the latter occurring when a fluid is propelled by either a current of air or an air pump. Lastly, radiation is the transfer of heat by means of electromagnetic emission. Hence giving rise to the concept of non-contact temperature measurements and the fundamental theory of infra-red and thermography technology.

The evidence of heat transfer occurs in the infra-red (IR) section of the electromagnetic spectrum between 0.75μm to 100μm. The radiated heat leaving a surface is termed as the radiosity and can be determined by the sum of the emitted, reflected or transferred components of electromagnetic radiation from the surface of an object in question.

The measurement of this radiant heat can be performed by the use of infra-red thermometers and or other thermal measuring devices, such as thermal cameras. Infra-red thermometers measure the amount of infra-red radiation being emitted from an object and transform the information into an electrical temperature measurement. Thermal imaging produces a representation of thermal energy being emitted from an object. The imaging is obtained from what is known as a thermography camera, which has a lens system that focuses the object's image onto an infra-red detector, where the image is produced for viewing.

Thermography can be utilised in either passive or active configurations. Passive thermography measures the temperature difference from a reference temperature, whilst active thermography uses another energy source to energise the components or surface of interest to be measured. Active thermography has many forms, such as pulse, step heating and vibro-thermography to name a few.

Points to be considered when making temperature measurements using infra-red techniques include the emissivity of the object, the size of the object's surface, the distance and medium between the object and the measuring instrument and the type of instrument being utilised.

2.9 Literature Review

The literature review investigated various instances of rolling stock bearing condition monitoring systems used in main stream and heavy rail industries, as well as any research that has been performed on the subject. The literature review also looked at current Australian Rail Industry Standards.

At present, CSR Sugar and the sugar industry are exempt from the Rail Industry Safety & Standards Board (RISSB) requirements, in relation to freight rolling stock wheel sets within the national rail system (The Rail Industry Safety &

Standards Board 2007). Hence, equipment within the sugar industry is not obliged to adhere to all legislative requirements as specified.

Li and Li (1995) discuss acoustic emissions developed from railway bearings and how their acoustic signals can be used to detect faults in axle bearings. They note that other acoustic systems exist and that improvements can be achieved by utilising a better signal analysis procedure. Li and Li (1995) then proceed to demonstrate and test their new algorithm through experimental means. The results show an improvement over current systems. Although this system has merit in improving current acoustic bearing condition monitoring, its experimental nature may not benefit the sugar industry requirements.

Vengalathur (2003) has researched a low cost fault detection system. His holistic approach is aimed at monitoring many rail car defects, including the axle bearings. He identifies that there are losses in the rail industry due to derailments and states that not all are due to bearing failures, not unlike the sugar industry. The basis of his research is to develop an onboard detection system to monitor many rail car defects. His system uses a series of accelerometers on the rail cars, producing vibration information which is processed on board, then sent to a master unit several rail cars along, via radio transmission and consequently logged for retrieval at a later date. This system is of interest; however problems may occur due to the harsh environment it may encounter, as well as industry requirements and the outlay costs.

Streets and Tse (1998) explain how Consolidated Rail Corporation (Conrail) has taken advantage of electronic equipment to detect faults in their freight trains. They monitor many components, one of which is the axle wheel bearings on their wagons. They have utilised two main systems other than the standard visual inspections of passing trains. They proceed to explain the uses of hot axle box detectors and acoustic bearing monitors, which are used with moderate to good success, hence stopping many bearing failures and derailments. Unfortunately, these systems are found to have drawbacks generating false alarms due to other factors unrelated to bearing failures. Many of these factors do not relate to the sugar industry, as cane bins do not have an on board braking system, thus false alarms due to brake problems will not exist.

Developments in advanced bearing acoustic conditioning monitoring (Southern, Rennison and Kopke, 2004) have provided other benefits related to this particular mode of monitoring. Advancements have enabled this system to detect other components' influences on axle bearings, for example, acoustic vibrations related to damaged wheels, can now be identified, avoiding bearing damage. Australian Rail Track Corporation (ARTC) and Vipac Engineers and Scientists Limited are the two companies that have combined to develop, design and install several of these particular systems, known as RailBAM©, within Australia and abroad. They are responsible for the dramatic reduction in the number derailments directly related to bearing failure, by trending bearing condition. As a proven and relatively successful system, RailBAM©, is seen to possess great potential towards solving CSR Sugar's rolling stock bearing condition monitoring problems. This system will be investigated further as a probable solution.

2.10 Conclusion

Whilst the sugar industry has evolved and undergone many changes, its basic operation and purpose has not altered. The need to transport the sugar cane from the surrounding fields to the sugar mills is the main function of the narrow gauge rail network and the rolling stock travelling upon it.

Due to the variation of cane bins in use throughout several districts, whereby each district has individual requirements and operating parameters, the sugar industry (CSR Sugar) has been obliged to adopt several systems to monitor the condition of rolling stock bearings.

The following chapter will describe the systems currently utilized to monitor the bearings on cane bins.

Chapter 3: Current CSR Condition Monitoring Systems.

3.1 Introduction

Currently, the seven CSR sugar milling sites employ a combination of the older and latest technologies to monitor cane bin axle bearing conditions. This chapter will identify the presently used methods, illustrate their basic workings and explain the advantages and disadvantages of the several systems currently employed within these sites, as well as their effectiveness in relaying and identifying potential problems.

3.2 Visual Inspections

Visual inspection is the oldest known and implemented method of determining the condition of bearings on cane bins. These methods are divided into two sections, the first being the ‘roll past’ method, which is primarily undertaken whilst the crushing is underway. The second method, the ‘bin by bin’ inspection, is the more comprehensive, as an individual visual inspection is conducted on the cane bins whilst they are in the maintenance workshop during the idle period of ‘slack season’. These two methods compliment one another as the crushing season roll past inspections rely heavily on the individual bin inspection during the slack season to identify and thereby address problems that may have manifested.

Roll past inspections are performed during daylight hours by technicians trained to detect any irregularities. These individuals are required to remain adjacent to the rail line as the rake of bins is drawn through by locomotive. Technicians are required to not only inspect wheel sets and hence bearing condition, but also general cane bin structural integrity.

Symptomatic criteria indicative of non compliant or suspected bearing failure may include bins that are observed as leaning, broken wheels/flanges and bent axles.

When a non-compliant bin is detected by the technicians, the bin identification number is recorded as a reference. This reference number is later used at the weigh bridge tippler, where the defective bin can be identified, unloaded and taken out of service. The defective equipment is then sent to the bin maintenance workshop for repairs.

Conversely the 'bin by bin' inspection is conducted during the mill's idle time and is by far a more comprehensive method of monitoring. This method requires an in depth individual inspection of all cane bins and is conducted in the cane bin maintenance workshop. These inspections are also carried out by appropriately trained personnel, who check various aspects of the cane bin for general integrity, in conjunction with performing one of the required periodical bearing lubrications.

The cane bins are raised on specifically manufactured hydraulic hoists allowing the underside to be examined. Particular attention is given to the cane bin wheels, axles, bearings and association components of the wheel sets by rotating the assembly manually, where various observations can be made to the bearings whilst the axles is rotating, therefore specifically noting the bearing condition. The signs of potential bearing faults include bent axles, cracked or broken wheels and damaged rubber suspension blocks. The use of this monitoring method allows the equipment to be checked thoroughly and components to be replaced as required. The obvious indications of bearing failure are the misalignment of the axle to the axle box (bearing housing), noises emanating from the axle box and a bent axle, all of which imply that bearing failure is imminent.

Figures 3.1, 3.2 and 3.3 illustrate the underside of the cane bin and its wheel set on the specific hoists used for maintenance and inspections.

Figure 3.1 Six tonne cane bin on hoist. (CSR Sugar)

Figure 3.2 Underside of six tonne cane bin. (CSR Sugar)

Figure 3.3 Four tonne cane bin wheel set. (CSR Sugar)

Due to an ever increasing bin fleet, 'bin by bin' inspections may not always be possible during the idle period, due to time and personnel constraints. The nature of these visual forms of inspections may result in technicians inadvertently overlooking possible bearing failures, resulting in non-compliant equipment being returned to service. As maintenance is no longer carried out to the degree that previous years saw, the roll past method is no longer as effective, as many of the cane bins show symptoms which are indicative of problems. This, in conjunction with the increased cane bin loading is taking a heavy a toll on the already aging equipment.

Whilst these monitoring systems remains in use, they are not the primary methods utilized for bearing condition monitoring in some sugar milling districts.

As opposed to alternative methods of bearing condition monitoring, the advantages to this particular system is that it is relatively inexpensive in relation to capital equipment outlays/investments, as it is primarily conducted through the use of human resources.

Conversely, this method may result in unnecessary maintenance to equipment as excessive preventative measures are conducted, hence increasing costs relating to rolling stock. An elevated cost, in conjunction with the declining number of appropriately trained personnel available within the industry has made this monitoring system inefficient.

3.3 Hot Axle Box Detection

At present there are only three of the seven CSR Sugar mills utilizing 'Hot Axle Box Detections Systems' to monitor the wheel bearing conditions of the cane bin fleets.

This system was implemented to improve cane bin maintenance. Several CSR Sugar mill sites have installed a Hot Axle Box Detector System (HABD) and a Radio Frequency Identification Tags (RFIDT) in an attempt to reduce unnecessary maintenance of cane bins in the idle period and to improve reliability. This system is currently used in other railway industries globally.

Essentially, the primary function of HABD is to detect hot bearings by measuring the temperature of the bearing housings, known as axle boxes. This is achieved whilst the cane bins enter the sugar mill in preparation for unloading.

The RFIDT fitted to each bin enables the system to identify individual cane bins through the tag readers mounted between the rail tracks. This in turn allows the HABD system, which incorporates infra-red temperature sensors mounted to both the left and right sides of the rail tracks, to monitor temperature. Figure 3.4 and Figure 3.5 illustrate the RFID tags mounted on the cane bins as well as the tag reader respectively. Figure 3.6 illustrates the general arrangement of the HABD system, while figure 3.7 depicts the position of the infra-red sensor in relation to the rail track.

Figure 3.4   RFID tag mounted on the cane bin.

Figure 3.5   Tag reader.

Figure 3.6 General arrangement of the HABD system.

Figure 3.7 Infra-red sensor, in relation to the rail track.

The information collated through this system is then recorded in relation to each specific cane bin. This data is then incorporated in the current weigh bridge tippler consignment information, which also includes the farm identification; cane variety and bin produce weight.

The bin bearing temperatures can be trended over a period of time and checked against operating parameters. If the temperature of an individual axle box exceeds a predetermined limit, an alarm will inform the weight bridge clerk that attention is required for that specific cane bin bearing. Hence, indicating the removal of that specific cane bin from service, with instructions for maintenance to be conducted.

Advantageous aspects of the HABD system include the more stringent control of bin greasing operations. Due to the deterioration of the grease lubricant through various factors, its effectiveness in reducing internal bearing friction diminishes, hence increasing bearing running temperatures. Therefore as this system is designed to detect temperature increases, it is capable of detecting problem wheel sets at an earlier stage prior to bearing failures. Other benefits of this particular system include the ability to build physical inspection records that illustrate the history of individual bin usage, the ongoing integrity of the equipment and record the age and condition of each bin, hence defining clear parameters in relation to bin maintenance requirements and replacement.

The data collated from the consignment records is utilized to develop an equipment service life history for each individual cane bin, which includes the distance travelled, the quantity of tonnes transported to the mill, the type of haul out equipment used within the field during loading and a corrosion allowance factor. The concept of the bin Loadometer, in conjunction with this data, enables a bin service life formula to be developed. The theory in relation to the bin Loadometer is essentially the tonnes per kilometre by the number of axles per bin. (tonnes x kilometres)/number of axles per bin. The formula that was developed is as follows.

Bin Life = Loadometer + Cycles at tip + corrosion + Haul out type.

As HABD utilizes electronic bin identification, it can support the ability to directly update data pertaining to individual cane bins once the required maintenance has been carried out in the maintenance workshop, retaining the bin service life information current.

Initial installation saw the alarm parameters set at 70°C. This was seen to be an effective temperature following preliminary testing, whereby any cane bin bearings exceeding this level would instigate an alarm at the weighbridge computer. The average quantity of cane bins handled per day during the harvesting season is approximately 4000 units. The 70°C temperature parameter would flag, or request removal from service, approximately 4 cane bins per day. In three months of operation, 202500 cane bins were tested with 364 bins taken out of service. Four were found to have total bearing failures that may have caused derailments. Of the 364 cane bins, 17% were found to have faults to bearing seals, lock nuts, locking washers or axles. Figure 3.8 illustrates the fault types found in the samples after inspections were conducted through the maintenance system and figure 3.9 illustrates the bearing temperatures taken over a three month period.

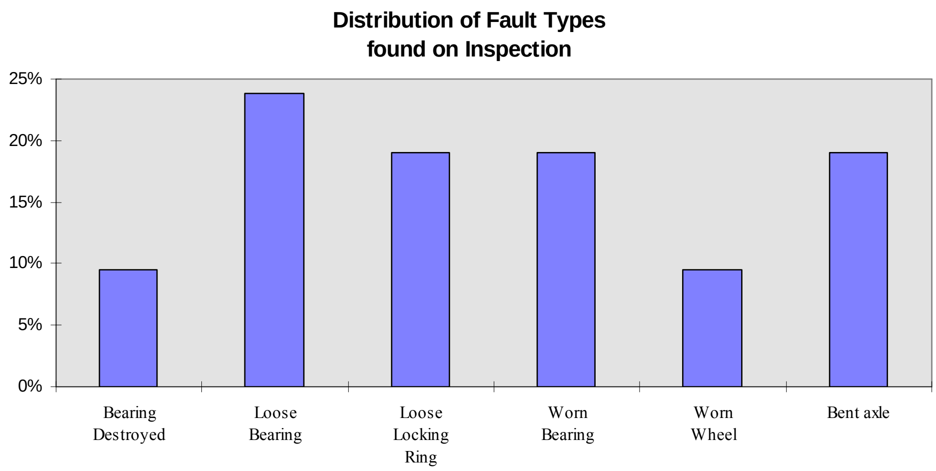


Figure 3.8 Distribution of fault types. (CSR Sugar)

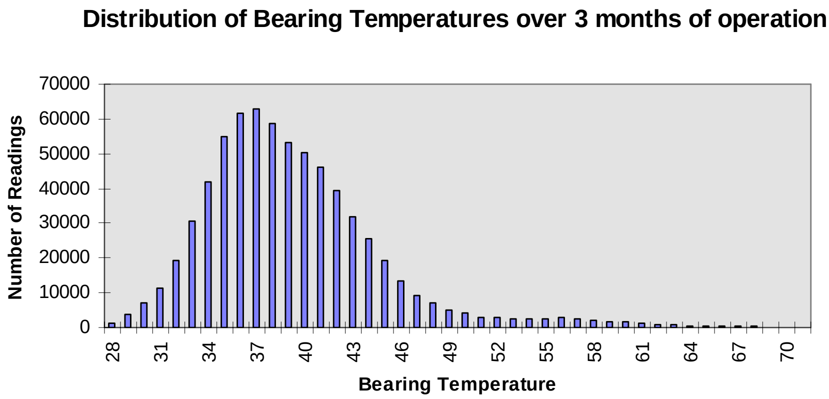


Figure 3.9 Distribution of bearing temperatures. (CSR Sugar)

Seasonal progression into the summer months created an elevated number of alarms. As ambient temperatures increased, the bearing temperatures were also affected, prompting changes to be implemented to the system parameters in an attempt to reduce the number of false alarms. These changes included the introduction of a temperature difference, as opposed to a maximum temperature, as an alarm parameter. That is, the axle box temperature is subtracted from the average of the ambient temperature from the left and the right sides of the cane bins. This adaptation was successful in reducing the number of false alarms, whilst continuing to maintain an effective monitoring system.

The system's ability to closely monitor bearing temperatures is advantageous; as rapid increases in temperatures are inherit to bearings nearing failure. It is imperative that testing is conducted as often as possible in order to maintain rolling stock integrity. This system is successful in detecting suspect wheel set components on fleet units prior to detrimental failures that may result in derailments.

Whilst this system is relatively successful, it does pose various disadvantages that unfortunately do not make the system infallible. The elevated false alarm rate is primarily due to several factors pertaining to temperature increases. These include the ambient temperatures that impact on readings taken, as well as the installation of new bearings that may also give inaccurate readings due to the bearing tolerances experienced regarding the internal radial clearances. Another aspect that impacts on the accuracy of this system relates to the speed at which cane bins can pass the temperature sensors. Any speed greater than 10km/hour renders the system incapable of obtaining accurate temperature readings, hence diminishing the effectiveness of the system to monitor cane bin axle bearings.

3.4 Thermography

Thermography is a relatively new concept to be introduced into the sugar industry. Various tests have been undertaken in recent years to ascertain if thermography could be a valid method of monitoring cane bin bearings. It has been successfully used in recent times by electrical departments in sugar mills to monitor electrical equipment.

At present the Herbert River Mills are the only sugar mills trialling the thermography camera for the purpose of monitoring cane bin bearings. In comparison to some of the other monitoring systems available, the thermography system is relatively simple in its application. Necessitating the employment of two technicians, the system incorporates the use of a hand held thermography FLIR© camera, which is the only component utilized to ascertain the temperature of passing wheel sets, as well a second technician to record bin identification data. The thermal image produced is the sole indicator of bearing temperature and hence condition.

Figures 3.10, 3.11 and 3.12 illustrate thermal images taken of cane bins and their respective bearings whilst travelling along the rail track.

Producing results that are favourably comparable to other systems, the thermography camera can also be sourced to other departments for use in alternative applications, maximizing its potential as a non-destructive testing tool. Thermography also delivers a greater level of accuracy in relation to the identification of potential components requiring attention. By clearly differentiating problem areas through the use of the images produced via testing, a more specific problem location can be attained. Whilst arguably faster than the hot axle box detectors and the above mentioned visual systems, the thermography system currently utilized does not give an overall comprehensive monitoring report as to the condition of the cane bin bearing.

Several other disadvantages can be identified with this system. As a manually operated system, thermography requires the employment of two trained technicians to operate, that is the camera operator as well as a second technician to record bin identification data. This raises the problem of the availability of human resources/staff that are appropriately trained in this system and who can be retained. As automation is not a factor within this monitoring system, data collated on problematic cane bin bearings does not reach the weighbridge reporting area, hence not allowing the identified faulty bearing/unit to be removed from operation for necessary maintenance.

As this system is reliant on temperature measurement, ambient temperature is of concern, as it is for the hot axle box detectors. For this system to be effective, considerations would have to be implemented to accommodate for the changes in ambient temperature. Similarly, temperature measurements in relation to internal radial clearances are also responsible for inaccurate diagnosis to problematic bearings. Lastly, whilst not imperative to temperature recording, images produced may not depict consistent colours in relation to temperature identification. That is, colours seen on one image indicating a particular temperature, may not correspond to the colours on another image with a similar temperature reading.

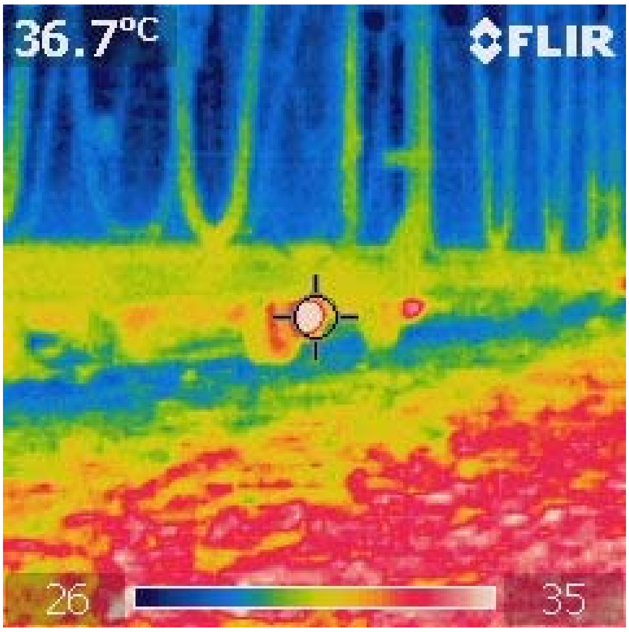


Figure 3.10 Bearing temperature image. (CSR Sugar)

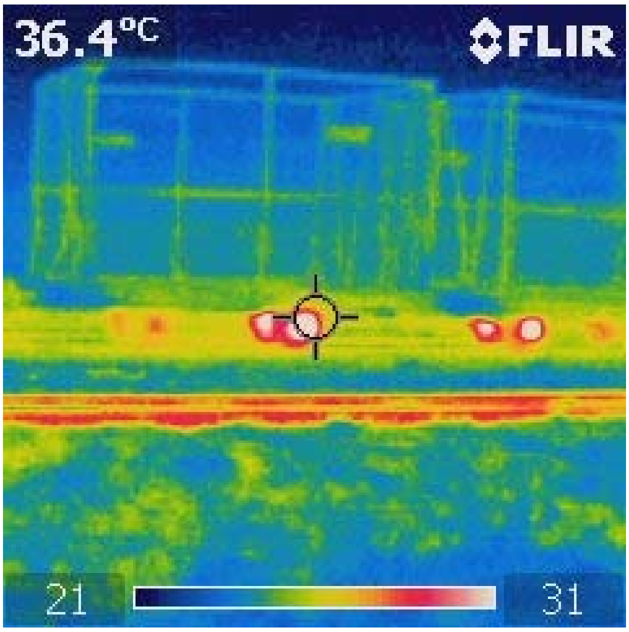


Figure 3.11 Bearing temperature image. (CSR Sugar)

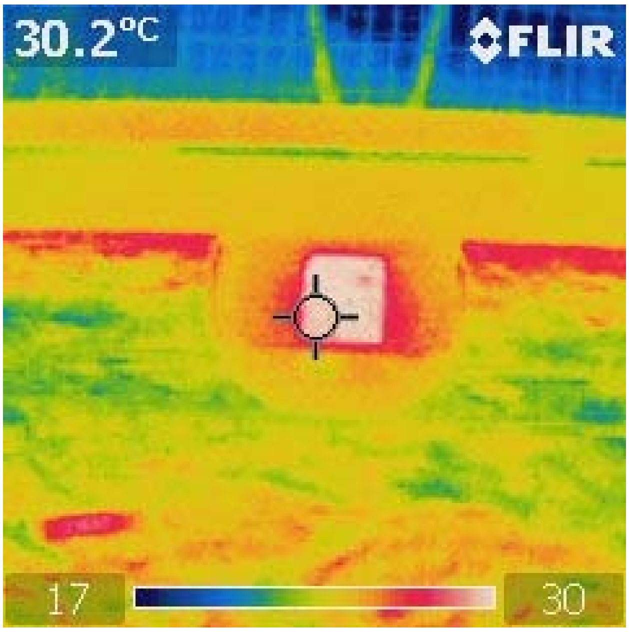


Figure 3.12 Bearing temperature image. (CSR Sugar)

3.5 Systems Used In Similar Industries

All global rail industries are similar in concept, in that they transport either passengers and or freight, making them directly related to the rail infrastructure used within the Australian sugar industry. However, there are obvious differences between freight/passenger trains and the trains utilised with in the sugar industry. These differences include the comparative physical size of the trains such as freight trains, the speed at which they travel and finally the frequency of use throughout any given period.

All train industries monitor rolling stock wheel bearings, as well as other components associated with the wagons, such as wheel and brakes. These systems aid in increasing the life of the equipment through better maintenance programs, which decrease running costs and increase profits.

Several systems currently used in other industries will be discussed in the next chapter.

3.6 Conclusion

The systems described in this chapter are a combination of new and older technologies. Whilst they are effective in monitoring rolling stock bearings to a specific standard, their disadvantages, the demand for a more effective technological solution and the requirements for best practices, necessitate modification or a replacement system to ensure a more reliable and safer operation. The following chapter will describe several other systems that are relevant and that may be adopted, as well as systems that are not practical, but exhibit relevant aspects to the task of bearing condition monitoring of cane bins.

Chapter 4: Alternative Condition Monitoring Systems.

4.1 Introduction

There are many methods in which to monitor bearings throughout various industries and in particular the rail industry. However, many systems are unsuitable to the sugar industry as they are primarily associated with fixed or stationery plant, such as pumps and power transmission equipment.

This chapter aims to give an overview of improvements that can be made to the current systems used within the sugar industry, as well as new systems, which may have the potential to improve condition monitoring of cane bin bearings, as well as being a cost effective solution to the current problems experienced.

Several of the systems mentioned within this chapter will undergo a cost analysis in the following chapter, to ascertain the most appropriate method to improve the current monitoring system. This is aimed at gaining the maximum safety and reliability potential of the current rolling stock as well as addressing the cost effectiveness of each.

4.2 Viability Criteria

To accurately ascertain the viability of the systems to be investigated, it is imperative that specific criteria be developed for the purpose of comparison. It would be necessary for the systems to be considered suitable at several different sugar milling sites, be adaptable to the monitoring of several different cane bin design types, as well as have the potential to be integrated into the specific operating systems currently employed with the industry.

Consideration would have to be given to the requirements and the changes necessary for implementation, that is, the ultimate use of the monitoring system to be introduced. The system to be considered for implementation would either be specifically employed to only identify damaged bearings or utilized as a complete data logging and trending approach of information collated from the equipment monitored. Should the latter be the direction that the industry wishes to undertake, it would be necessary to decide whether the data logging and trending continues to it full potential once calibration and commissioning has been implemented.

Additional points to be considered include the geographical position of the monitoring system in relation to the milling site. This allows the system to maximize the quantity of bearings monitored, hence identifying the greatest number of problematic bearings. This criteria factor is particularly pertinent, as several of the current milling sites presently only operate using one access tramway into and out of the mill. Conversely, other milling sites have multiple entry and exits points. This poses the problem of cane bin accessibility and frequency over the monitoring equipment, which may be placed in a stationary position, hence minimizing the monitoring effectiveness. Inaccurate readings may also occur when the bearing housing exterior is coated in materials such as grease or mud, therefore inhibiting and or restricting the effectiveness of the monitoring equipment. The speed of the passing cane bins also attributes to the accuracy or inaccuracy of the monitoring system, as some current methods are incapable of measuring the bearing condition within the cane bin fleet under excessive speeds. It is also to be noted that in several of the sugar mills the orientation of the cane bin may alter after the unloading process has been completed, that is the left side of the bin on entry may become the right side of the bin on exit. Due to the nature of the industry, the implementation of any monitoring systems would also have to allow for the regular and necessary uncoupling and re-coupling of the cane bins at the milling site.

Based on the above criteria several systems will be investigated and assessed in their suitability for implementation within the sugar industry.

4.3 Hot Bearing Warning Bolt

This system is essentially a concept with a United States patent and was viewed on the Patent Storm website (2008). It is presently not a commercially manufactured product, however it has the potential to be utilised in a variety of applications throughout various industries. Should evidence prove that apparatus of this nature would be of benefit to the sugar industry, steps could then be undertaken to acquire these particular pieces of equipment.

The Hot Bearing Warning Bolt is used to secure the bearing housing covers. It is of hollow construction and filled with a temperature susceptible compound, which holds a compressed spring. Once the pre-determined temperature is reached, the compound breaks down releasing the spring that acts on a plunger and indicating pin. This pin pushes a cover plate off the head of the bolt leaving the indicating pin exposed until the bolt is replaced. This approach indicates that the bearing has reached the pre-determined temperature and in all probability requires replacement due to damage.

A visual inspection would be required to identify damaged bearings. This could be undertaken in two different manners. The first requires two technicians, one on either side of the cane bins, observing each as they roll past. The second would be to use a close circuit television to monitor the images of the passing wheel bearings on a screen. Both methods require the technicians to make note of the defective cane bins.

Presently there are a percentage of the older cane bins that do not possess the cover plates, as the older bearing types have slip on bearing housings. Therefore the Hot Bearing Warning Bolt could not be implemented in these situations. As a non-automated system and relying heavily on human resources, this system's accuracy is completely reliant on consistent visual accuracy. As the bolt is a relatively small piece of equipment, any outside influences that may occur would impact on the ability for technicians to accurately identify the bolts' condition. This coupled with the speed factor; greatly diminish the successfulness of such a system. This system is not designed to identify imminent bearing failure, but only bearings already damaged; therefore this monitoring method is considered useless from a preventative maintenance perspective.

This system will not be considered for rolling stock cane bin conditioning monitoring despite being a relatively simple concept. Many aspects attribute to this statement. The first being it unavailability, due to the fact that presently it remains a non-commercial product, hence the elevated cost associated with the manufacture of such a product in minimal quantities make it an unappealing alternative. Its inability to identify imminent bearing failure, its size in relation to the cane bin geometry, the visual obstruction that may be encountered due to extraneous materials and lastly the level of human error that will occur.

4.4 SKF Rail Bearing Monitoring Systems

SKF is a global bearing manufacturing company that is at the forefront of bearing technology and associated components and has a vested interest in delivering safe and practical solutions to its customers.

One of their many divisions include the global rail industry, where SKF strives to maximize the performance of their rail bearings to economically benefit their clients, as well as delivering safe bearing condition monitoring solutions to protect passengers and crew on rail services around the world.

Having developed a bearing condition monitoring system that is used throughout Europe in its high speed trains, SKF provided a solution to the problems associated with rail wheel bearings and their monitoring. The basis of its condition monitoring is the installation of specifically designed bearings adapted with sensors on train wheel sets. These bearings can measure rotational speed, direction of rotation and bearing condition through the monitoring of operating temperatures. This bearing is shown in figure 4.1.

Figure 4.1 SKF rail bearing with sensors. (SKF website, 2008)

This system continually measures the bearing temperature and hence the bearing condition. The bearing temperature information collected by the sensors is sent through to the on board temperature monitoring device, which in turn sends a high bearing temperature alarm to the operators if a bearing becomes abnormally hot.

Whilst this system functions extremely well and has relevance to the operation, its appropriateness for its implementation into the sugar cane industry is unsuitable due to several factors. To enable this system to be applied to cane bins, it would require the replacement of all existing bearings currently within the fleet. This would be an extremely costly exercise which would not be financially viable. Due to their specific size and geometry the implementation of these bearings is not appropriate to this application. Lastly, due to the necessity of the information being passed via communication cables, the application is not suitable due to the requirements of the cane bins to be uncoupled and re-coupled several times per day.

4.5 Hot Axle Box Detectors

There are numerous rail companies globally that utilize Hot Axle Box Detection technology (HABD). Whilst this technology has been in use for some time, recent software developments have seen marked improvements in it application. Several Australian companies develop, market and install systems for rail industries through the country and internationally. One of these systems has already been utilized by three of the sugar mills in the CSR Sugar milling group. Discussion on the general working of one of the systems was undertaken in chapter 3. This system illustrates that it is a functional and practical solution to the task of bearing condition monitoring. However, the HABD systems currently in operation have several flaws that hinder the effectiveness towards being the ideal solution to the ongoing rolling stock integrity. It is for this reason that the Hot Axle Box Detectors are being investigated again. Many new innovations and improvements have been made, which have greatly improved the efficiency and accuracy of HABD systems.

One of the Australian companies at the forefront of this development is Inspired Systems. They have developed a system named ARGUS (ARGUS. The watcher who never sleeps, 2008). The ARGUS system has been developed to be a stand alone unit capable of operation in the harsh conditions of the resource industries. This system essentially employs a similar concept to the system currently in use, whereby temperature measurements of axle boxes are recorded as they pass the infra-red temperature sensors.

The basic configuration of this system comprises of a hot axle box detector and radio frequency identification tag (RFIDT) readers, mounted adjacent to the tracks and a hot wheel temperature sensor. Through the use of the identification tag, each wagon can be isolated and corresponded to the relevant temperature recorded from the hot axle box detector. Hence, information collated through this system can accurately partner each wagon number to the relevant temperature recorded for each bearing. This information is filtered back to the track side processor, housed within a structure known as a hut, which is located nearby. The hut also houses the communication system that is responsible for the delivery of the gathered information to the relevant operation department. The system alerts the operation department to wagons with elevated and excessive bearing temperatures requiring attention. Therefore removal of the damaged wagon can be executed and maintenance conducted.

One of the key features of the ARGUS systems is the track side intelligence unit, which identifies the passing wagon and assists in organizing collection of data. The track side intelligence unit also has the ability to perform self checks and to notify the relevant personnel of any malfunctions or errors, via the communication system. Whilst the ARGUS system is fundamentally similar to currently employed HABD monitoring equipment, in as much as an alarm is raised when a pre-determined temperature set point above the ambient temperature is reached. It is a far more sophisticated and robust unit, having been developed for the mainstream rail freight industries to focus on the rail wagon braking systems as well as the bearings. The wheel temperature sensing feature can detect sliding or over-braking wheels, as well as wagons whose brakes are not operating correctly and are identified as cold wheels. Unfortunately this feature is not a requirement for the monitoring of sugar cane bins, as they are not equipped with individual braking abilities. Sugar cane bins rely on the brakes situated in the brake van located at the end of the rake, or bin line, to assist in decreasing their speed and enabling them to come to a stand still.

The ARGUS system can be readily applied to the monitoring of sugar cane bin bearings with minimal disruptions to the present rail infrastructure, however for optimum operation it is imperative that the units be placed on level and straight sections of rail track. The addition of a trending analysis tool, such as the OSCAR system, also produced by Inspired Systems, will enhance the ability to monitor and maintain a history of the cane bin fleet. Such systems gather information from various sources, such as the ARGUS system and collate the data into reports with historical data. This data can be used as an early warning system to protect and enable maintenance schedules to be planned. Whilst the OSCAR system may be complimentary to the ARGUS system and the monitoring of cane bin bearings, it is fundamentally similar in principle to the current data collating system.

The stand alone ability of the ARGUS system provides several advantages over current systems as the cane bins can travel past the infra-red temperatures sensors at a much greater speed than the maximum of 10 km/h of the existing HABD system. This allows the bearing temperature reading to be taken whilst the bearings are at their maximum operating speed, which in turn enables a more accurate and consistent reading to be recorded. This reduces the number of false alarms, or conversely damaged bearings to slip through the system, due to the cane bins having to slow down, therefore potentially loosing a percentage of heat in the process.

As several sugar mills have more than one rail entry point ,due to the geographic nature of the districts in which sugar cane is grown, the ability of this system to be relocated periodically would be advantageous. Unfortunately all HABD systems are positioned in fixed locations, therefore making this one disadvantage to the system. Future design considerations may encompass the ability of a system to be portable, hence far more useful and adaptable to the sugar cane industry as it stands at present.

Figures 4.2 and 4.2 illustrate an operational Inspired Systems ARGUS system.

Figure 4.2 Operational ARGUS system track side components. (Inspired Systems)

Figure 4.3 ARGUS system trackside electronics. (Inspired Systems)

4.6 Vibration Analysis Applications

One of the oldest, most reliable and widely used forms of bearing condition monitoring systems is vibration analysis. This system is used in an array of industries and is present in various forms, such as fixed or portable units.

It has proven to be an effective tool in giving early warning of bearing failures when used to monitor bearings in service, allowing planned corrective actions to be undertaken successfully.

While there is not a commercially supplied system utilising vibration analysis to monitor fleets of axle wheel bearings, a tailored system may be adapted for the task. The following is a conceptual design that may be modified to monitor bearings on cane bins. In general, to effectively utilise vibration analysis for bearing condition monitoring, the bearing of interest should be in service, under an applied load and rotating at operating speed, or conversely a known speed, sufficient to enable a constant, accurate and timely reading to be taken. Additional bearing information, such as the type and manufacturer, are also required to successfully and accurately analysis bearing condition, as the variation between rolling elements within bearings differs between manufacturers.

The basic concept of the proposed system would be to take readings on loaded cane bins prior to the unloading stage, where the cane bins have been uncoupled and separated. The cane bins would pass over a testing apparatus, which would rotate the cane bin axle bearings, via wheel rotators, utilising either a hydraulic or electrical system. Accelerometers located on the loaded side of the bearing housings would acquire the vibration readings of each bearing simultaneously, as the wheels are rotated at a pre-determined speed.

The equipment envisioned to take the readings would be a series of accelerometers and the components to record and send information to be processed and logged. The equipment of interest is supplied by the bearing manufacturing company SKF and can be readily obtained and adapted to the application.

After consultation with an SKF representative, the equipment best suited to an automated system is a combination of a multi-parameter sensor, which measures both vibration and temperature, these are individually identified by the SKF product code CMPT 2310T (SKF website, 2008), transmitters, with product code CMPT CTU (SKF website, 2008), which process the signals and send them to the alarm display modules, with product code CMPT DCL (SKF website, 2008). These alarm display modules can be programmed to alarm at specific points of concern. The transmitter can also be utilised to send information to a personal computer, where it can be analysed and logged using specific software. The minimum number of components this system would require is eight sensors, eights transmitters and sixteen display modules to monitor one eleven tonne cane bin. It is to be noted that the alarm display modules may not be required if the system is to be directly linked to a personal computer. Due to the variation in cane bins, the raising apparatus must be adaptable to allow re-configuration. At this point it is to be noted that the testing apparatus is a conceptual design. Figure 4.4 illustrates the design concept and only shows one cane bin. The testing apparatus will be able to test two cane bins and a maximum of eight bearings simultaneously. The testing apparatus will have to be reconfigured to test the several models of cane bins in service when required. That is, the positions of the wheel rollers and accelerometer adaptors will be altered to conform to specific cane bin type geometry.

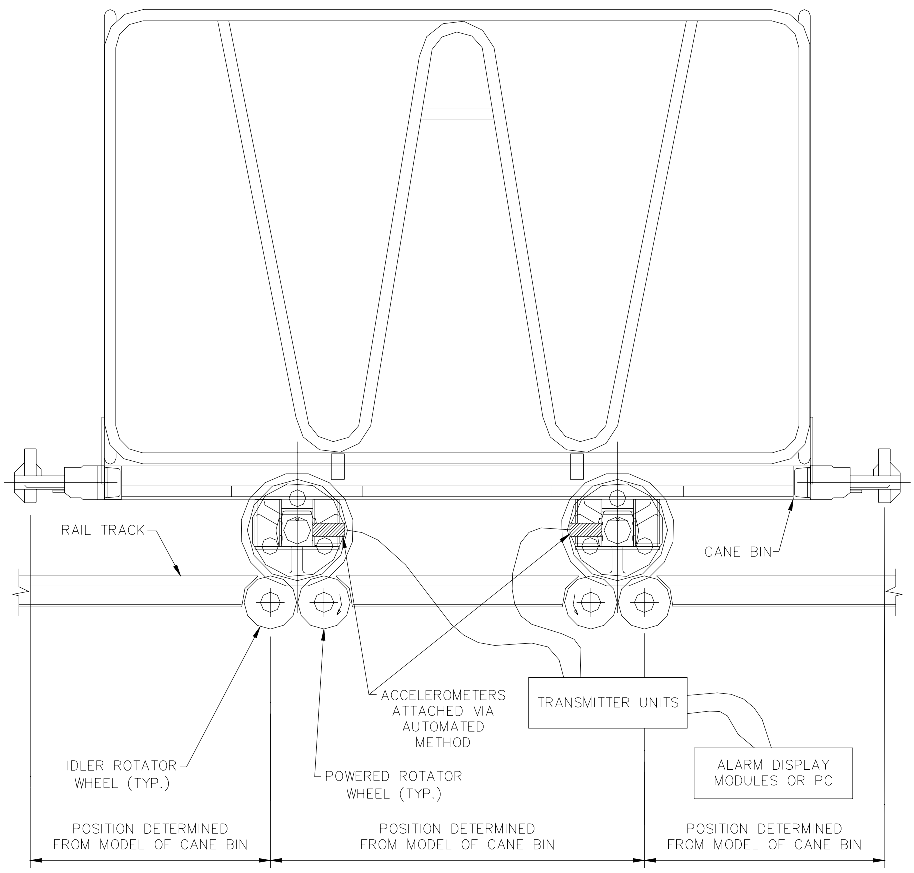


Figure 4.4 Conceptual design of vibration system.

The advantages of this type of system are that it can be adapted to be portable if required, enabling it to be re-located to alternative sites, as well as facilitating the trending of bearing conditions and substantial prior warning of bearing failures.

The disadvantages of this vibration analysis system include the present lack of a bin identification system, which enables bearing information to be partnered with the correct bin. The fact that there are presently several types of bearings in service from various manufacturers compounds the problem, as historic data relating to cane bins and their bearings has not been maintained, therefore the correct identification of bearings per bin must be a known factor. The correct placement of the accelerometer, by means of an automated method, may pose difficulties as incorrectly placed accelerometers will give erroneous readings. It is vital that a pre-determined test speed be known, as vibration frequencies are heavily reliant on correct speed identification. Other disadvantages would be the speed at which it would operate, as the available time in which the system may perform the monitoring function is below sixty seconds. In this time the loaded bin would have to be located on the testing apparatus, accelerometers attached, the wheels rotated and the information gathered. The reversing of this procedure would also be required to be undertaken within the same sixty second time period, to allow the bin to continue to the unloading station with out causing delays to the factory.

Whilst this system has potential, it requires a substantial amount of research and development to gauge a better understanding of its effectiveness and functionality. The adaption of an automated cane bin identification system such as radio frequency identification tags and readers would also need to be considered.

4.7 Acoustic Bearing Monitoring

Recently adopted technologies have seen the introduction of acoustic analysis to monitor bearings on rail wagons. This system identifies and utilizes the acoustic signature emanating from operational wheel bearings, in an attempt to isolate defective or damaged components. As briefly discussed in chapter 3, the technology relies heavily on modern software to enable it to segregate and differentiate between the various acoustic signals obtained, to accurately identify problems.

Vipac Engineers and Scientists Limited have developed the RailBAM© system, for use in monitoring rail wagon bearings, using acoustic monitoring technology. Their systems are presently being utilised both nationally and internationally. This system has the ability to identify the various sounds emanating from passing train wheels sets, using specialised equipment and computer software.

The basic configuration is to have specifically constructed microphone stations on both sides of the rail tracks, which are connected to sensors activated by approaching trains, which in turn activate the microphones by opening the protective shutters that cover them. The system also incorporates a radio frequency identification tag (RFID) reader, which is used to identify the passing wagons and wheel detectors, aiding in the processing and location of faults. The microphone stations are illustrated in figure 4.5.

Figure 4.5 Microphone station. (Vipac Engineers)

The RailBAM© system has the ability to monitor wheel bearings at train speeds of between 30 km/h and 130 km/h in either direction. The system consistently differentiates between the various sounds, identifying bearing and wheel defects, wheel profile and tracking problems associated with wheel sets. Figure 4.6 illustrates an operational RailBAM© system.

The information collected is sent to the enclosed structure adjacent to the rail tracks, which houses the computer system. At this point the information is analysed via proprietary techniques. Proprietary techniques differentiate between the various acoustic signatures from the numerous operating components and categorise the severity of bearing condition. The results are then forwarded, via IDSN (Integrated Services Digital Network) to the client's data base within fifteen minutes of the train passing. It is at this point that any defective wheels sets are flagged for maintenance and repair.

The data base can be utilised to trend wagon information spanning several years, through the compilation of historical information, which is useful for future reference. As the system is capable of identifying bearing defects at their earliest stages, it reduces the potential of bearings failings in service through an improved maintenance program.

Figure 4.6 An operational RailBAM© system. (Vipac Engineers)

The system can be adapted to monitor cane bin bearings. The main concern would be the speed at which the cane bins are travelling, as most cane trains will only reach a maximum of 30 km/h at any given time. Although an adequate bearing speed is required to obtain consistent readings, this problem may be alleviated as cane bins have relatively small wheels in comparison to the main stream rail industry. Due to their size, cane bin wheels are rotating at a greater speed, hence the bearings will also be rotating accordingly, allowing the RailBAM© system to perform its function at an acceptable level. Unfortunately the smaller sized wheels on the cane bins require the microphone stations to be adapted to enable facilitation of this application. As the bearings are lower to the track, it is essential that the microphones are positioned lower in their configuration to enable correct readings to be taken.

One of the primary advantages of this system is that it operates as a stand alone unit, allowing it to be installed in an optimal position throughout the railway network in each sugar milling district.

There appear to be few disadvantages for the RailBAM© to be implemented in the sugar industry, other than its inability to be relocated to other sites, however further research and development may alter this with respect to future demands.

4.8 Thermography

The relatively new technology of thermography is being utilized in many industries and disciplines. The primary application of thermography is associated with electrical equipment, where electrical joints and major components can be monitored effectively through the measurement and actual placement of temperature elevations, however it has been found to be useful in mechanical applications also.

There are several manufacturers of thermography equipment, one of which is FLIR©, who produce many different models of thermography cameras for a wide range of applications and costs.

Whilst thermography has been trialled in Europe , by mounting a thermography camera to a rail wagon to monitor the temperature of specific rolling stock wheel bearings (FLIR© website, 2008, FLIR© Application Story), no definitive results have been reached in relation to its application to the monitoring of sugar cane bins bearings in Australia. Although thermography technology was applied within one of the sugar mills, as mentioned in chapter 3; the basic approach was insufficient to adequately illustrate the long term benefits of such a system. To date there have been no developments in relation to this system to monitor fleets of axle wheel bearings on rolling stock. However, a system may be tailored to the sugar industry and the following discussion will present one concept which may be applied to the monitoring of cane bin bearings.

As both sides of the cane bins must be monitored to capture the all the bearings, an additional thermography camera would be required unless an adaptation can be found. This is in the form of the placement of the camera, that is, only one camera may be required if the camera is positioned at a 45 degree angle to the rail tracks and at a maximum distance of ten metres from the further most bearing to be monitored, as shown in figure 4.7 below. This configuration reduces the costs associated with this system. However, the ability of the thermography camera to measure the temperature of the furthermost bearing can be affected by the wheel obstruction, as well as the maximum speed at which the cane bins travel by the camera, therefore inhibiting the collection of accurate bearing temperature readings.

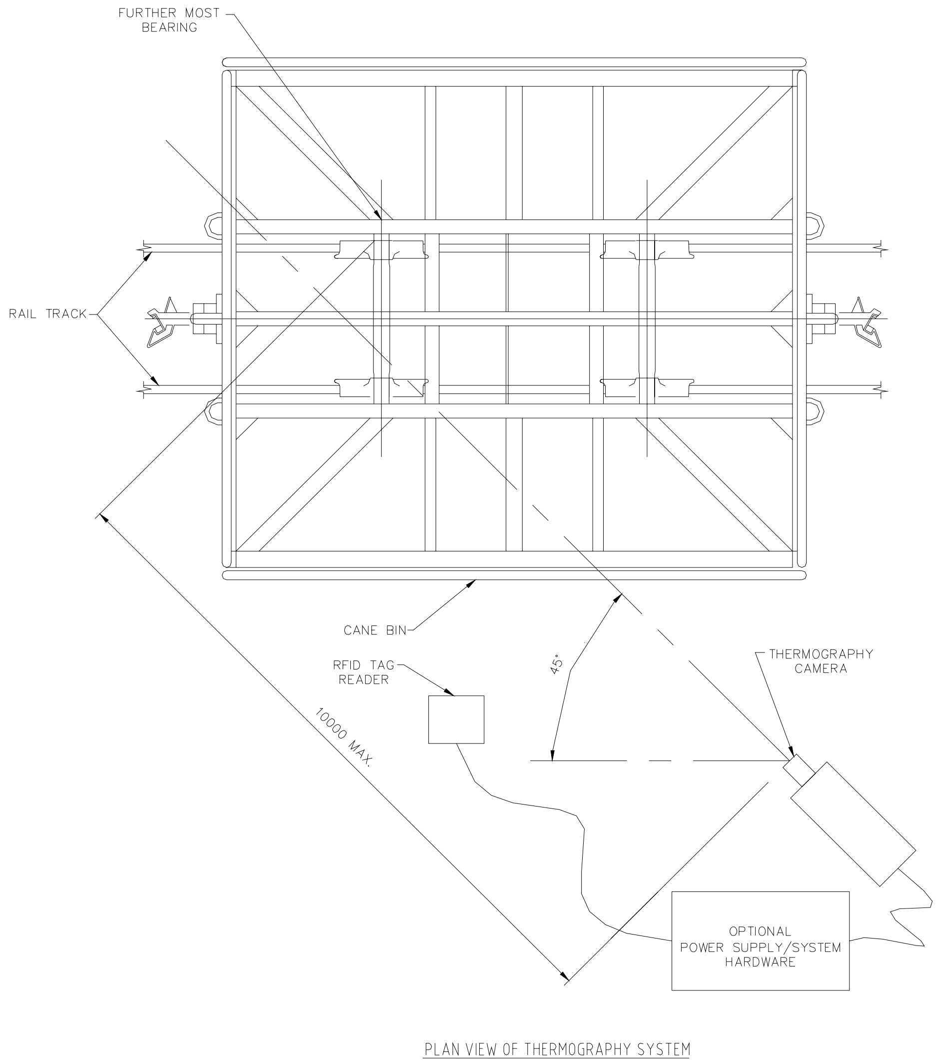


Figure 4.7 Conceptual design of thermography system.

The images shown in section 3.4 were taken by a FLIR© hand held thermography camera. Whilst this instrument is relative to the task, it does not meet the requirements of being a stand alone system and necessitates two operators. After consultation with the manufacturer, it was determined that a FLIR© A320 thermography camera was best suited to the application (refer to appendix D for specifications). Figure 4.8 illustrates the FLIR© A320 camera.

Figure 4.8 FLIR© A320 thermography camera. (FLIR© website, 2008)

The A320 camera does not require an operator and is best suited to continual monitoring; a necessary requirement if this is to be considered as a possible system to be implementation.

The possible configuration would see the camera mounted in a specifically manufactured protective casing and connected to a power source, being either 12 or 24 volt, produced via transforming mains power or an on site power supply (Batteries). The images produced may be processed by the accompanying computers and software installed to support the system and powered similarly to the camera. The data collated may be either manually retrieved from the unit, or additional technological equipment utilised to transmit the information to relevant departments for review.

The possible portability of this system is advantageous, as various locations may be utilised to monitor a greater number of fleet units. Unfortunately, as this system does not facilitate the identification of individual cane bins, elevated bearing temperatures would be bin unspecific. The incorporation of an identification system, such as radio frequency tags, currently used in other monitoring systems, would be required to be integrated in to the overall system, enabling specific bin identification.

Factors that inhibit the accuracy of such a system include the train speeds, as speeds in excess of 10 km/h would begin to distort the images produced, creating difficulties in accurate data processing. This occurs as the A320 camera utilises a microbolometer to measure temperature and has a response time of 12 milliseconds. The ends of the bearing housings are approximately 150mm in size; this reduces to a target size of 75mm at the 45 degree design angle. At 10 km/h, the bin will move approximately 30mm in the 12 milliseconds, producing a distorted image. External coatings of mud and or grease on the bearing housings would also impact on the accuracy of this system, due to changes in the emissivity.

4.9 Lubrication Sampling

Bearing lubrication sampling is also a method to monitor bearings. This system undertakes periodic sampling of the grease lubricants used in the cane bin bearings. These may show evidence of microscopic wear particles, which occurs as bearing and seal wear escalates and may be indicative of potential bearing failure. This method has proved to be invaluable in applications, such as the monitoring of power transmission units and other hydraulic systems. However, due to the magnitude of bin fleet numbers, the availability of bins due to service requirements and the period for the return of conclusive results, this method is impractical and unfeasible for the required application within the sugar industry. It will not be given further consideration as a successful monitoring system within this project, due to the logistic requirements.

4.10 Bin Recognition

Whilst this section is not directly associated with the monitoring of cane bin bearings, it can be appreciated in previous sections that tailored condition monitoring systems have one major disadvantage in that they do not facilitate an automated cane bin recognition system.

As most of the monitoring systems currently in use utilize a radio frequency identification tag system, this would be an obvious choice as the preferred recognition system. However, every cane bin has a unique identification plate, not unlike an automobile number plate, mounted to both sides. Figure 4.9 illustrates an example of a unique identification plate.

CSR has been researching a camera recognition system that has the ability to read and differentiate between cane bins via this plate. While this technology is currently in the research stage, it has the potential to reduce cane bin and bearing recognition problems, making the tailored monitoring systems a more attractive alternative in relation to mainstream monitoring systems.

Figure 4.9 Example of a cane bin unique identification plate.

4.11 Conclusion

Of the six systems reviewed in this chapter, only two, the ARGUS and the RailBAM© are currently being utilized to monitor rolling stock bearings in other industries and would be best suited to the task related to this project. The vibrations analysis and thermography approaches are of conceptual design and require much more research. The following chapter will investigate the viability of the four systems by conducting a cost analysis.

Chapter 5: Cost Analysis.

5.1 Introduction

The previous chapter described several systems that may be a solution to the problem of effective and efficient bearing condition monitoring or rolling stock. Of these the hotbox detection and the acoustic monitoring are the only fully developed and operational systems currently being utilized. The use of vibration analysis and thermography are to be also considered, if a tailored solution can be implemented. In this chapter a cost analysis will be performed on the four above mentioned systems, as well as a bearing replacement system, to determine the most viable system that may be implemented.

5.2 Derailment Costs

To conduct a cost analysis and determine the viability of a system or technique, one must first know the cost savings in implementing such a system. Hence, as this project focuses on the wheel bearings of cane bins, their impact in relation to the cost that damaged bearings have on the industry, must be determined. The consequences of a failed bearing have many implications, such as derailments, the down time, the loss of production to the sugar mills and related costs. Figures 5.1, 5.2 and 5.3 illustrate a derailment, which may have been caused by a failed bearing.

Figure 5.1 Example of a cane bin derailment. (CSR Sugar)

Figure 5.2 Example of a cane bin derailment. (CSR Sugar)

Figure 5.3 Example of a cane bin derailment. (CSR Sugar)

The cost of a serious derailment as indicated above, can amount to many tens of thousands of dollars, therefore an average of these costs must be determined for further analysis.

The costs of derailments have slowly increased, due to production and labour costs increases. Figure 5.4 illustrates the cost of derailments and the increasing trends for the years between 1997 and 2001.

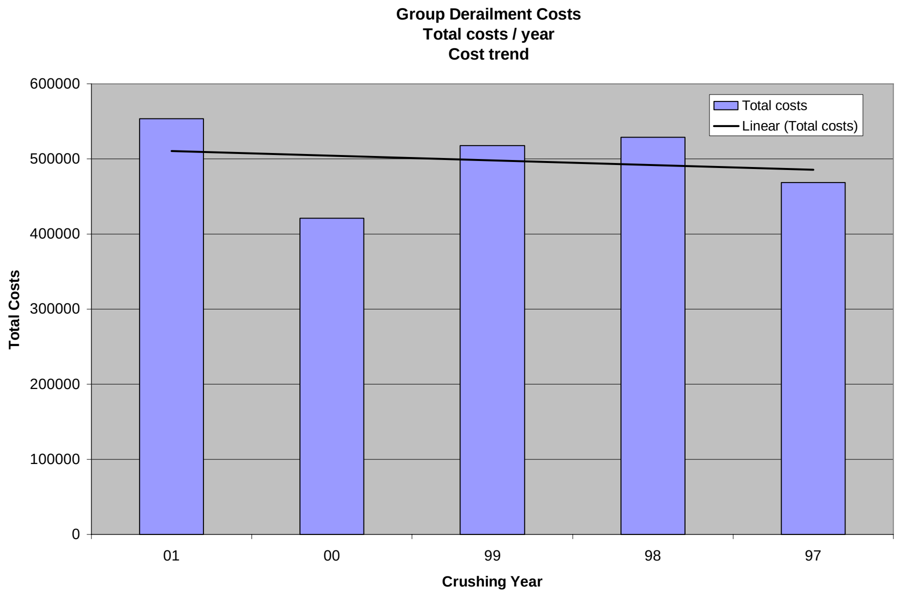


Figure 5.4 Costs of cane bin derailments. (CSR Sugar)

There are many causes of derailments and these are divided in several categories, two of which included operator error and bin failures. The latter is of particular interest to this project. Figure 5.5 illustrates one of CSR Sugar's yearly derailment statistics for two of their mills in one district for the 2004 and 2005 seasons. Table 5.1 illustrates the sub-categories of the bin faults illustrated in figure 5.5.

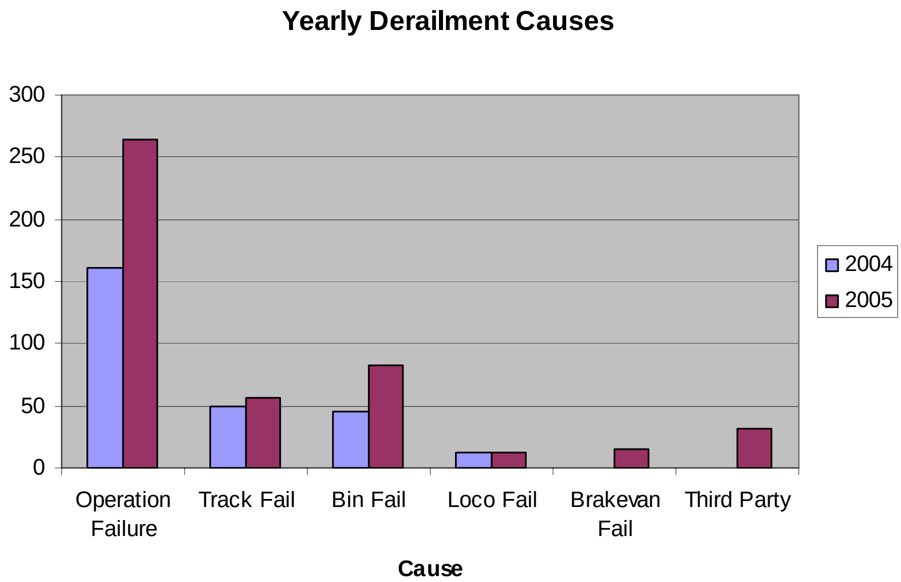


Figure 5.5 Yearly derailment causes. (CSR Sugar)

Bin Faults	**2004**	**2005**
Coupling Failure	6	4
Bearing Failure	32	28
Bin Frame	0	5
Wheel Failure	6	28
Chassis	2	2
Other	0	15
Total	46	82

Table 5.1 Bin fault sub categories.

From figure 5.5, it can be seen that bin faults contribute to a relatively small number of derailments, when compared to operation failures, being by far the major cause. However, when considering the derailments caused by bin failure, it can be seen that bearing faults are the major contributor, as compared to other causes. As illustrated in table 5.1, bearing faults or failures for the year 2005 can contribute to a minimum of approximately 34% of all bin fault derailments, which is 16% of an average of seventy-three derailments throughout this period as illustrated in figure 5.5. The bearing failures contributed to sixty derailments in the district of interest during 2004 and 2005 seasons. This equates to an average of thirty derailments per year within the district.

The cost of a derailment is very difficult to ascertain, as the majority of incidents are minor and require few resources and time to rectify. However, very large derailments can be very costly and require many hours to clear and repair the rail track. The information given by CSR Sugar illustrates that the cost of a derailment can range between $2000 for minor incidents to $50000 for major derailments, with the average cost being $24000.

It is to be stated that there are very few major derailments and the average of $24000 per derailment is not a realistic figure for the following cost analysis, therefore an assumption is to be made to determine a derailment average cost. If each of the derailments and their costs were to be plotted as a normal distribution curve, the curve would not be symmetrical in shape. Figure 5.6 illustrates the possible normal distribution curve, together with a standard normal distribution curve.

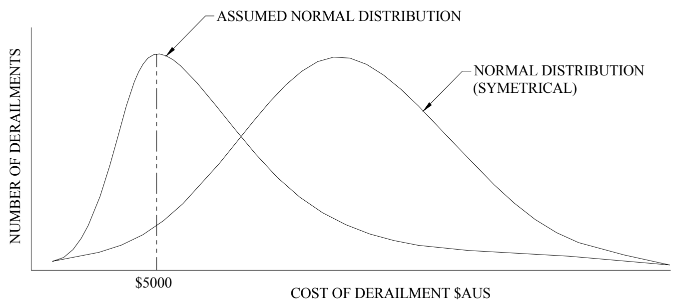


Figure 5.6 Possible normal distribution.

For the purpose of this project the assumed average derailment cost will be taken as $5000 per derailment. Taking the average number of bearing fault related derailments to be thirty derailments per district, then the potential saving for the district by implementing a bearing monitoring system for the purpose of monitoring of cane bin bearings, is as follows:

Indicative cost saving/yearly/district = $5000 x 30

= $150000

It is to be noted that the district that is indicated in this calculation has only two sugar mills, whilst other districts have up to four mills, making an overall average difficult to obtain without all of the information.

In the following sections a cost analysis will be undertaken for several systems, with the costing to be conducted on the monitoring on a set number of cane bins. In this project that number will be taken as eight thousand units, which is the approximate number of cane bins in the district with two sugar mills. This number is required, as the cost of purchasing and installing radio frequency identification tags must be known to give an indicative total costing. The pay back, or return on investment, required to define if a system's installation is feasible must be less than five years.

It is to be noted that the prices of the following systems have not been received through a formal quoting process but are indicative of the retail prices from the various suppliers of the equipment. Several of the costs associated with the tailored systems have been assumed and are indicative only.

5.3 Hot Axle Box Costing

There are two hot axle box detection systems that may be considered. The first being a similar system to the one presently being utilized by other sugar mills in the CSR Group and the second is the Inspired Systems ARGUS system as discussed in Section 4.5. The basic cost analysis for the above mentioned systems will illustrate the capital outlay and return investment.

5.3.1 Current HABD System

The basic requirements for the currently utilized HABD system by CSR Sugar are in table 5.2 below. This costing is based on the last installation of a HABD system in a sugar mill and is indicative only. Additional costs may be incurred.

Requirements	**Costs excluding GST** **$ AUS**
Tag reader system	15000
Current HABD unit	45000
Bin RFID tag for 8000 units @ $25/unit	200000
Installation of RFID tags @ $5/unit	40000
Basic electrical costs	23000
Computer interface	22000
Civil works	7500
Ongoing costs	-
Total	352500

Table 5.2 Current HABD costing.

The return on investment of this system is calculated as follows:

Where *IC* is implementation cost and *CS* is cost saving.

$$\frac{IC}{CS} = \frac{352500}{150000} = 2.35 \text{ years}$$

Therefore return on investment is less than five years, making this system viable for installation.

5.3.2 ARGUS System

The cost of the ARGUS system includes the license, third party hardware and software as well as installation and training. The basic requirements for the ARGUS HABD system are illustrated in table 5.3 below.

Requirements	Costs excluding GST $ AUS
ARGUS system costs including • Pre-installation analysis • Site civil works • Solar equipment • Enclosure (Hut) • Hot Bearing and Wheel Detectors • Track side intelligence unit • Voice radio to driver • RFID identification system • Communication system	300000
Bin RFID tag for 8000 units @ $800/unit	6400000
Installation of RFID tags @ $5/unit	40000
RFID tag programmer	16000
Ongoing costs	-
Total	6756000

Table 5.3 ARGUS HABD costing.

The return on investment of this system is calculated as follows:

Where *IC* is implementation cost and *CS* is cost saving.

$$\frac{IC}{CS} = \frac{6756000}{150000} = 45 \text{ years}$$

Therefore return on investment is greater than five years, making this system not viable for installation.

It can be seen that the cost of installing the current system is far less than that of the ARGUS system, however the more sophisticated ARGUS system has far more advantages, such as having the ability to take readings at greater speeds than that of the current system and should be seriously considered for the application if the purchase price of the RFID tag can be reduced.

5.4 Vibration Analysis Costing

The cost of the proposed vibration analysis system includes the conceptual design, manufacture and installation of the cane bin testing apparatus. The system is to be assembled from various components and the basic requirements, as well as their costs for the vibration system, are illustrated in table 5.4 below.

Requirements	Costs excluding GST $ AUS
Vibration components • 8 x CMPT 2310T accelerometers. • 8 x CMPT CTU transmitters. • 16 x CMPT DCL alarm display modules. • Additional junction boxes.	20000
Tag reader system	15000
Bin RFID tag for 8000 units @ $25/unit	200000
Installation of RFID tags @ $5/unit	40000
Basic electrical costs	23000
Computer interface	22000
Civil works	200000
General costs	20000
Ongoing costs	-
Total	540000

Table 5.4 Vibration analysis costing.

The return on investment of this system is calculated as follows:

Where *IC* is implementation cost and *CS* is cost saving.

$$\frac{IC}{CS} = \frac{540000}{150000} = 3.6 \text{ years}$$

Therefore, return on investment is less than five years, making this system viable for installation, however it requires further research before the system can be implemented, as it has not been proven for the application. Additional costs may be incurred during the research.

5.5 Acoustic Bearing monitoring (RailBAM©) Costing

The cost of the RailBAM© system includes software, as well as installation and training. The basic requirements and costs of a RailBAM© system are illustrated in table 5.5 below.

Requirements	Costs excluding GST $ AUS
RailBAM© system costs including • Track side units x 2 • Wake up sensors • Train presence sensors • Wayside enclosure (Hut) • Thermal disconnect boxes • Computer rack • Uninterrupted power supply • RFID identification system • Communication system • Weather station (pole mounted)	560000
Additional civil costs	450000
Bin RFID tag for 8000 units @ $55/unit (minimum required)	440000
Installation of RFID tags @ $5/unit	40000
RFID tag programmer	16000
Ongoing costs	Up to 7% per year
Total (not including ongoing costs)	1506000

Table 5.5 RailBAM© costing.

The return on investment of this system is calculated as follows:

Where *IC* is implementation cost and *CS* is cost saving.

$$\frac{IC}{CS} = \frac{1506000}{150000} = 10.04 \text{ years}$$

Therefore return on investment is more than five years, making this system unviable for installation.

5.6 Thermography Costing

The cost of the proposed thermography condition monitoring system includes the conceptual design and software requirements. The system is to be assembled from various components and the basic requirements, as well as their costs for the thermography condition monitoring system, are illustrated in table 5.6 below.

Requirements	Costs excluding GST $ AUS
FLIR© A320 thermography camera	30000
Camera protection housing	9000
Camera software (if required)	1900
Tag reader system	15000
Bin RFID tag for 8000 units @ $25/unit	200000
Installation of RFID tags @ $5/unit	40000
Basic electrical costs	20000
Computer interface	22000
General costs	20000
Ongoing costs	-
Total	357900

Table 5.6 Thermography system costing.

The return on investment of this system is calculated as follows:

Where *IC* is implementation cost and *CS* is cost saving.

$$\frac{IC}{CS} = \frac{357900}{150000} = 2.39 \text{ years}$$

Therefore, return on investment is less than five years, making this system viable for installation, however, as the system has not been proven for the application; further research is required before the system can be implemented. Therefore additional costs may be incurred during the research.

5.7 Bearing Replacement Costing

A bearing life of 28 years was calculated in section 2.6 and it was stated that the calculation was based on a continuous load application. While this may be acceptable for normal bearing life in perfect conditions, many factors as discussed in section 2.7, reduce the serviceable life of a bearing. One proposition would be to change the bearings at predetermined time intervals, as an alternative to a condition based monitoring system. These intervals would be much shorter in duration than the calculated bearing life, to minimise bearing failures. The following is a cost analysis of a bearing replacement program that may be utilized by replacing bearings at periodic intervals. The same sample number of 8000 cane bins will be used in the analysis.

The program scope would be to change the bearings on approximately 500 cane bins per year, with a sixteen year full fleet bearing replacement cycle. It is assumed that this would be done during the idle period, so as not to introduce an added out of service cost in the harvesting period. Another assumption made in the following cost analysis is that only the bearings would be replaced and that all other wheel set components would remain in service. The following cost information has been given by CSR Sugar and is based on the cost of replacing wheel bearings on a four tonne bin:

Requirements/Costs		**Costs excluding GST $ AUS**
Items and No. Required/Bin	**Component Cost**	
Bearing. 4 required	$50	200
Wheel set. 2 required	$860	1720
Miscellaneous costs	-	50
Total / Cane bin		1970
Total for 500 cane bins		985000

Table 5.7 Bearing replacement costs.

The return on investment of this programme is calculated as follows:

Where *IC* is implementation cost and *CS* is cost saving.

$$\frac{IC}{CS} = \frac{985000}{150000} = 6.57 \text{ years}$$

Therefore, return on investment is more than five years, making this proposed bearing replacement programme unviable for consideration. It is also to be noted that this programme would require the capital investment shown above for sixteen consecutive years totalling $1576000. Hence this programme will not be considered further.

5.8 Conclusion

The cost analyses conducted in this chapter has given an insight into the amount of investment and expected return of each of the new systems. All the systems, excluding the bearing replacement programme, employ the appropriate technology for a continuous, automated, condition based, monitoring programme. Table 5.8 illustrates the results obtained in the research. It can be seen that the current HABD system, along with the vibration and thermography systems are the most cost effective, whilst the ARGUS and RailBAM© systems are the most appropriate for the application.

System	Cost $AUS (Excluding GST)	Return on investment (Years)	Appropriate technology	System automation	Identification system required	Train speed compliant	Relocatable
ARGUS	6,756,000	45	Yes	Yes	Yes	Yes	No
Existing (HABD)	352,000	2.35	Yes	Yes	Yes	No	No
RailBAM©	1,506,000	10.04	Yes	Yes	Yes	Yes	No
FLIR© (Thermography)	357,900*	2.39	Yes*	Yes*	Yes	No	Yes
Vibration	540,000*	3.6	Yes*	Yes*	Yes	N/A	No

* States conceptual design

Table 5.8 New systems research results.

Chapter 6: Findings and Recommendations.

6.1 Introduction

This chapter concludes the project work undertaken on bearing condition monitoring of rolling stock used in the sugar industry. A summary of the research conducted, as well as recommendations and further work will be discussed.

6.2 Project Summary

The aim of this project was to review the current CSR Sugar bearing condition monitoring systems and to research the suitability of other systems with a view to improving the current bearing condition monitoring program. The aim and objectives have been achieved, with the currently used systems and their associated problems having been identified and several new condition based monitoring systems having been researched. The systems researched are considered to perform continuous and automated monitoring of cane bin bearings.

The FLIR© thermography and vibration systems would require further research and development to be considered for this application. The thermography system is the same in principle to the hot axle box detection system, in that they both measure the temperature of the wheel bearings. However, the thermography system has the potential of being relocated, adding to it its versatility. The vibration system will most likely not be appropriate for the monitoring of the wheel bearings, as problems may arise with any automated attachment techniques associated with the accelerometers. Environmental factors, such as dust or mud as well as grease, covering the axle boxes will also reduce the ability of the accelerometers to be attached correctly. Hence the effectiveness of the system will be reduced, as erroneous vibration readings will be produced.

The disadvantages of the new systems researched include the cost of implementation, particularly noting the cost of some recommended radio frequency identification tags being sourced from several system manufactures, as it was found that there was a significant price difference between tag units. Another disadvantage is the inability of the major systems to be easily re-located if required, making them less attractive to the application, as their mobility would allow the systems to be utilised in other districts, hence increasing their versatility.

The most viable systems, in relation to cost, were found to be the currently used hot axle box detection system, the vibration and the infra-red thermography systems. However, the last two require further research and development before the system can be implemented, which may escalate the costs of these systems illustrated in this report.

The ARGUS and RailBAM© systems can be seen to be the most effective for the application and the most technologically advanced. However, their present cost of implementation poses concern in a struggling industry.

6.3 Further Work

Further work is required to reduce the cost of the radio frequency identification tags, which will make several of the new systems researched a more viable option for installation within the sugar industry. This may include using radio frequency identification tags that are not recommended by the condition monitoring system manufacturer, but rather alternative tags that would still be suitable for the application of monitoring of cane bins.

Further work into camera recognition technology may be an alternative to the radio frequency identification tags, allowing the system to still trend bearing condition information.

Additional work is required to developed formal specifications for the new condition based monitoring systems researched, which are appropriate for the application to the sugar industry. The RailBAM© and ARGUS systems may benefit from a more comprehensive cost analysis, therefore allowing the implementation of these systems to become financially attractive.

6.4 Conclusion

Research into the current CSR Sugar rolling stock bearing condition monitoring systems has been undertaken, as well as research into other automated condition based monitoring systems, with the potential to improve the current preventative maintenance programs. Their viability and applications have been discussed and recommendations given. Whilst any improvements to the current systems or implementation of the new systems discussed will significantly reduce in service bearing failures, the systems will not totally eliminate bearing problems. However, the new systems discussed are effective tools in maintaining rolling stock integrity. The outcomes of this research will facilitate CSR Sugar to make informed future business decisions.

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Appendix A: Project Specification.

Faculty of Engineering and Surveying

Courses ENG4111/4112 RESEARCH PROJECT Part 1 & 2

Project Specification 2008

Student: Alfio Lamari

Student No.: 0038970158

Supervisor: R Fulcher

Sponsor: CSR Sugar

Title: Rolling Stock Bearing Condition Monitoring Systems

Aim: To review current CSR Sugar rolling stock bearing condition monitoring systems and to research the suitability of other systems and techniques with a view to improve current preventative maintenance programs.

Objectives:

1. To undertake a literature review of rolling stock bearing condition monitoring techniques and systems.
2. Define and describe current system of bearing condition monitoring and benchmark systems within the industry and other industries with similar equipment.
3. Identify significant problems with current systems of bearing monitoring and failure prediction.
4. Propose solutions to the identified problems by discussing alternative techniques and their suitability to the application.
5. Conduct a cost benefit analysis of the suggested solutions.
6. Write a dissertation of the project work which includes a report of the findings to the sponsored company.
7. If time permits, report on any implemented solutions.

Student: **Date:** 12-03-08

Supervisor: R. Fulcher **Date:** 28.03.08.

31-03-08

Appendix B: Safety Concerns.

Whilst the content of this research project is theoretically based, there is a practical element in relation to safety adherences that are a compulsory factor when considering site visits to sugar mills.

These site visits are a necessary procedure to view the equipment of interest to this project, namely the cane bins. Visits will also provide a clearer understanding of how the currently implemented systems function, as well their effectiveness. The site visits will also give an appreciation of how other systems being researched could be applied, either as stand alone systems or in parallel with current systems, to enhance their ability to fulfil the bearing condition monitoring requirements.

In undertaking these above mentioned site visits, there is a degree of personal safety which one must be aware of. As a visitor to any site, it is imperative that the rules and regulations imposed by the company are followed, these being a combination of site specific rules and the Australian Standards and Workplace Health and Safety Legislation, 1995. These rules are a likened to other similar industrial factories and are implemented to ensure the safety of all personnel and visitors.

The duty of care stated in the Workplace Health and Safety Legislation applies to both the employer and employee. The employer has a duty of care to provide a safe workplace and the employee has a duty to minimise any risks which he or she may encounter performing their daily work tasks. To minimise the risk to one self, many avenues are taken, for example using and maintaining personal protective safety equipment provided by the employer and completing a risk assessment (job safety analysis) prior to commencing work.

As a visitor, I also have a duty whilst undertaking the site visits. Below is a risk assessment for my planned site visits to the sugar mills. The hazards that maybe encountered are stated and the controls required minimising or eliminating any injuries to me or others. Also included is a generalised risk assessment of a cane bin derailment.

It is to be noted that this risk assessment will be reviewed several times during the course of this project to include any other hazards that may be encountered and their controls.

RISK ASSESSMENT

Derailment	**Likelihood**	**Exposure**	**Consequence**
Risk: 1. Cane bin derailment due to poor general maintenance and sequential clearing of wreckage and repair of infrastructure.	Almost certain	Occasionally	Serious
Controls:	New Risk scores		
1. Evaluate causes. 2. Implement a more efficient monitoring and maintenance programme	Possible	Likely	Serious

Table B1 Risk assessment No. 1.

Site Visits	**Likelihood**	**Exposure**	**Consequence**
Risk: When on site: 1. Exposure to locomotive and cane bin traffic movement.	Almost certain	Occasionally	Serious
2. Slips, trips and falls especially on the uneven ground along side track and the ballast on the track.	Almost certain	Occasionally	Serious
3. Unsecure bins on hoist falling whilst inspecting underside of cane bin.	Possible	Occasionally	Serious
4. Exposure to general workplace hazards.	Almost certain	Occasionally	Serious
	New Risk scores		

Controls: 1. Correct supervision	Almost certain	Occasionally	Important
2. Be aware of surroundings and wear correct PPE	Almost certain	Occasionally	Important
3. Unsure cane bin is secured correctly and ask for confirmation.	Possible	Occasionally	Minor
4. Use correct PPE.	Almost certain	Occasionally	Minor

Table B2 Risk assessment No. 2.

Appendix C: Resource Requirements.

As with most research projects, resources have to be obtained. This project will require the minimum of resources due to the style and the nature of the chosen topic.

Very few items have to be purchased and will be done so by myself. These will be basic items, such as measuring and photographic equipment which will be used on various site visits.

The main resource requirement of this project will be to gain access to several of the sugar milling sites. This will be achieved through contacting the relevant individuals who are capable of granting access to said sites.

These site visits must be undertaken to view the various cane bin types and the rail infrastructure, to appreciate the working of the current systems and to be able to establish probable locations for proposed, new equipment which may be utilised.

Any other resources will be supplied or negotiated with the company prior to any site visits. This will include the use of any instruments and the individuals trained to operate them.

It has been stated that very few resources are needed to undertake this project and the access to several sugar mill sites has already been granted to myself, on the provision of appropriate supervision and guidance.

Appendix D: Specification for FLIR© A320.

FLIR SYSTEMS
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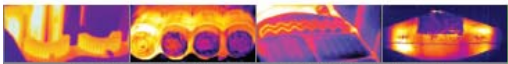
NEW! ThermoVision® A320

INDUSTRIAL AUTOMATION IR CAMERA



The A320 is an affordable and accurate solution for machine vision and automation systems that require non-contact imaging and temperature measurements. It is a complete machine vision and remote monitoring system that immediately identifies thermal problems that would otherwise go undetected. Its built-in logic makes it ideal for safety/security systems, and for product and process monitoring in quality/reliability assurance programs.

- Affordable, Fully-integrated Thermal Measurement Solution
- Multiple Target Spots and Alarms
- Plug-and-Play Compatibility
- Real-time Analog and MPEG-4 Digital Video Output
- Stand-Alone Operation, No PC Needed
- Multiple Users can Access Data from Multiple Cameras
- Maintenance-free, Uncooled, Microbolometer Detector

Find Faults Quickly

Finding and resolving problems early can save thousands of dollars by resolving safety issues, cutting down on scrap and warranty costs, and improving product quality. The A320 can spot subtle temperature variations undetectable by any other means. These can be easily monitored with its thermal imaging, temperature alarms, and actual temperature readouts.

Instant Non-contact Temperatures

The A320 is designed to deliver accurate thermographic imaging and repeatable temperature measurements in a wide range of automation applications. Each thermal image is built from 76,800 individual picture elements that are sampled by the camera's on-board electronics and software to measure temperature. The real-time 16-bit 320x240 image data can be used to monitor and help control a production process, or can be processed by the camera's on-board intelligence to autonomously generate multiple independent digital alarms. Digital video transmissions are facilitated using MPEG-4 compressed image format.

Outstanding Imaging and High Thermal Sensitivity

From the beginning, the A320 was developed to deliver accurate radiometric imaging and repeatable temperature measurements. It features an advanced, uncooled microbolometer focal plane array (FPA) detector that delivers crisp, longwave images in a multitude of palettes. Temperature variations as small as 0.08 °C can be detected.

Extensive Connectivity Options

Multiple A320s can be networked through their 100baseT Ethernet connections, and synchronized through the SNTP protocol. Each camera can be assigned a unique IP address for detection and data exchange on a network. FLIR's IR Monitor software can be used with a PC for camera control, configuration and monitoring via the network. This also provides instant access to A320 thermal images and temperature data by any authorized user via LAN/WAN. In addition, alarm messages can be sent by email to a remote location using the SMTP or FTP protocol. Wireless connection options are also available.

Plug-and-Play Setup

The A320 features plug-and-play setup. Simply connect the camera to a PC monitor and immediately view high quality, real-time radiometric thermal images that accurately show heat patterns and thermal anomalies. Alternatively, images can be viewed on a standalone video monitor by using the camera's composite video output (NTSC or PAL).

Easy to Configure and Operate

The user-intuitive A320 is extremely easy to operate. Its onboard logic and menu-driven controls enables users to select and manipulate multiple target spots, temperature range, image color palettes, multiple alarms and more – quickly and easily. Adding IR imaging to a machine vision system is no more complex than adding a visual image camera. Moreover, the A320 provides a simple way to create command and control programs through its bundled IR Config and IR Monitor software modules.

Easier Program Development

FLIR supplies multiple tools for developing customized programs that help monitor and control processes with the A320 Series. These include the ThermoVision™ LabVIEW® Digital Toolkit and ThermoVision™ System Developers Kit (SDK). In addition, the Digital Toolkit enables the easy creation of a machine vision or measuring application with a FLIR IR camera within National Instruments LabVIEW programming environment. The SDK is an ActiveX component with methods, properties and events that allows Visual Basic/C++ developers to control FLIR cameras and convert incoming IR images to temperature images.

Ultra-compact, Rugged and Lightweight

Built to operate unattended for long periods in harsh industrial environments, the A320 has an IP40 rating. Its compact design and light weight (less than 2 lbs.) allow it to be mounted in remote locations that may be optimal for data collection. By taking advantage of Power Over Ethernet (POE) capabilities, local power supplies are not needed. Fully configurable GPIO and V-sync functionality allows the A320 to be integrated quickly and easily into machine vision and automation systems.

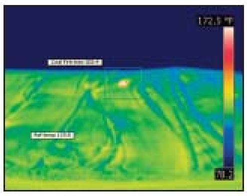
ThermoVision® A320 Specifications

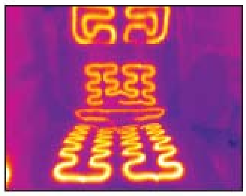
Imaging Performance	
Field of View	Built in 25° × 18.8°/0.4 m (1.3 ft.)
Focusing	Auto focus, motorized manual
Detector Type	Focal Plane Array (FPA), uncooled microbolometer
Spectral Range	7.5 to 13.0 μm
Pixel Resolution	320×240
Measurement	
Temperature Ranges	−20°C to +120°C (−4°F to 248°F) 0°C to +350°C (32°F to 662°F) Optional up to +1200°C (2192°F)
Accuracy (% of Reading)	±2°C or ±2%
Image Presentation	
C-video	PAL/ NTSC (25/30 Hz or 9 Hz)
MPEG-4	RTSP/ RTP/ UDP Frame rate: dependent on image quality set (compression&size)and available network bandwidth Image size: 640x480/320x240/160x120.
16-bit Signal w. Radiometric data, FLIR proprietary 16-bit signal TCP/IP (DirectX) 16-bit temp linear TCP/IP (DirectX)	Frame rate: Maximum (7.5-8.5 Hz)/ 5 Hz/2 Hz/1 Hz/0.5 Hz/0.2 Hz, 0.1 Hz. Image size: 320x240/160x120. What's achieved is dependent on image quality set size and available network bandwidth and CPU load
I/O Functionality	
Digital out: 2 Outputs, Opto-isolated,10-30V supply, 100 mA	Alarm (Internal temp, Analog in, digital in) Program ctrl.
Digital in: 2 Inputs, Opto-isolated, 10-30V	Batch enable Store image ALARM Mark image (start/stop/time)

ThermoVision A320

1. **Composite Video:** PAL/ NTSC
2. **100 Mb Ethernet:** Supporting TCP/IP protocol and WEB-server, http. MPEG-4 streaming. Power over Ethernet.
3. **Power Connector, ScrewTerminal 2-pole:** 12/24 V, 12W.
4. **Digital I/O Connector, ScrewTerminal 6-pole:** Digital Out: 2 outputs, opto-isolated, 10–30V supply, 100 mA. Digital In: 2 inputs, opto-isolated, 10–30V.

Environmental	
Operating Temperature Range	−15°C to +50°C (+5°F to +122°F)
Storage Temperature Range	−40°C to +70°C (−40°F to +158°F)
Humidity (operating and storage)	IEC 60068-2-30/24 h 95% relative humidity +25°C to +40°C (+77°F to +104°F)
Encapsulation	IP 40 (IEC 60529)
Bump, Operational	25 g (IEC 60068-2-29)
Vibration, Operational	2 g (IEC 60068-2-6)
EMC	EN 61000-6-2:2001 (Immunity) EN 61000-6-3:2001 (Emission), FCC 47 CFR Part 15 Class B (Emission)
Physical Characteristics	
Weight, total for operational system	0.7 kg (1.54 lb.)
Size, Camera body including handle, L × W × H	170 × 70 × 70 mm (6.7 × 2.8 × 2.8 in.)
Base Mounting	2 × M4 thread mounting holes (on three sides)
Tripod Mounting	UNC 1/4"-20 (on three sides)
Included Components	
Power supply 90-220V AC in, 12V out	Part No. 1910585
Power cable	Standard 2-wire w/ground
Power cable to Camera pigtailed	Part No. 1910586
Video cable	BNC, 2m
Ethernet cable	CAT-5e, 2m
Utility CD with drivers	IP Config and IR Monitor programs
Accessories	
Telephoto lens, 15-degree	1196724
Wide angle lens, 45-degree	1196725
Hard case	1196940
ThemoVision SDK Toolkit	
ThermoVision LabView Toolkit	
ThermaCAM Researcher, v2.9 Basic	
ThermaCAM Researcher, v2.9V Professional	





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Appendix E: Vibration System Component Specifications.

CMPT 2323 and CMPT 2323T
Low profile integral cable accelerometers

SKF® CMPT 2323 and CMPT 2323T models are piezoelectric accelerometer sensors especially made for monitoring low speed machinery (n < 40 r/min) operating in harsh industrial conditions, such as horizontal grinding mill trunnions, vertical grinding mill rollers (tyres), roll crushers, press rolls, etc.. The sensors have greater sensitivity and lower-frequency measurements capability than CMPT 2310 and CMPT 2310 models.

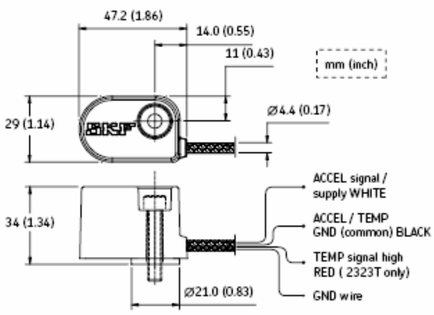
The CMPT 2323T model includes a precision integrated circuit temperature sensor. The CMPT 2323T temperature output voltage is linearly proportional to the temperature (ºC) and does not require external calibration or trimming to provide high accuracy over the full 0º to +120 ºC temperature range.

The CMPT 2323 and CMPT 2323T sensors are hermetically sealed in a stainless steel body and have an integral stainless steel wire over-braided cable. The sensors have a low profile housing and a side exit integral cable for use in a wide range of industrial applications where harsh operating conditions and limited mounting space prevail. The stainless steel and hermetic construction makes them suitable in corrosive and wet environments. The sensor cable is double insulated and highly resistant to abrasion and wear. The sensor cable has excellent signal transmission characteristics, low capacitance, redundant shielding and high mechanical durability. The transducer and internal cable shield/ground are isolated from the sensor housing to prevent ground loops. The sensor mounting base and fastener (included) are compatible with industry standard accelerometers.

Features

- 230 mV/g sensitivity
- 0,2 Hz low frequency cut off
- CMPT 2323T includes an integral temperature sensor (10 mV/ºC)
- Rugged design, stainless steel hermetically sealed sensor housing
- Integral 5 m (16 feet) stainless steel wire over-braided twisted shielded cable
- Straight forward sensor interface with color-coded cabling
- Standard mounting techniques, utilizing a low profile side exit cable with recessed mounting screws
- The internal sensor capsule is isolated from the machine ground
- Low noise, highly shock resistant, and overload protected electronics.

SKF



Specifications

Specifications conform to ISA-RP-37.2 (1-95) and are typical values referenced at +24 °C (+75 °F), 24 V DC supply, 4 mA constant current and 80 Hz.

Sensor – Accelerometer (CMPT 2323 and CMPT 2323T)

Sensitivity: 230 mV/g

Sensitivity precision: ± 10%

Sensitivity deviation over full temperature range: 10% (approx.-5% at -50 °C and +5% at 120 °C)

Amplitude linearity: < 1% up to full scale

Transverse sensitivity: < 5% of axial

Acceleration output range: 70 g

Shock limit: 5000 g

Accelerometer measurement temperature range: -50 to 120 °C (-58 to 248 °F)

Sensor – Temperature (CMPT 2323T)

Sensitivity: 10 mV/°C

Temperature measurement range: 0 to 120 °C (32 to 248 °F)

Precision: ± 1,5 °C

Electrical

Power requirements

Voltage source: +24 V DC nominal, +18 to +30 V DC

Constant current diode: 4 mA DC at +24 V. 2 to 10 mA is permissible.

Acceleration sensor bias voltage: 11,5 V DC ± 10% for +24 V DC supply at 25 °C

Over voltage protection: At approximately 18 V DC

Reverse polarity: (Wiring) Protection installed

Cables: Integral cable, 5 meters (16 feet) length

Acceleration sensor electrical noise level: < 1 mG RMS broadband 2,5 Hz to 25,0 kHz

Wire spec.: 0,32 mm^2 (AWG 22) stranded tin copper (7 strands @ 0,05 mm2 each)

Grounding/shielding: Case isolated, internal shielding (faraday cage), faraday cage connected to power supply return

Wire connections – CMPT 2323

White: ACCEL signal/power (connected to Constant Current Source)

Black: ACCEL signal Ground (GND)

Blank twisted wire: Screen connected to internal shield

Wire connections – CMPT 2323T

White: ACCEL signal/power

Black: ACCEL/TEMP signal Ground (GND)

Red: TEMP signal high

Blank twisted wire: Screen connected to internal shield

Environmental

Maximum operating temperature: 140 °C (284 °F)

Storage temperature: -50 to 150 °C (-58 to +302 °F)

Vibrations limits: 70 g peak

Shock limit: 5 000 g peak

Electromagnetic sensitivity, equivalent g: < 100 micro g/Gauss at 50 to 60 Hz

CE: According to the generic immunity standard for Industrial Environment EN50082-2

IEC: 529, IP67

Physical

Weight: Sensor without cable 210 gram (8 oz)
Sensor with cable 410 g (14.4 oz)

Sensor housing material: 304 stainless steel

Hardware: (1) M6×1 socket head cap screw (30 mm long) included, and
(1) 1/4-28 UNF socket head cap screw (1.25" long) included

Screw torque: 6 Nm (50 inch-lbf)

See www.skf.com for more information.

Publication 4954 E-11 11/2004

SKF alarm and display module (CMPT DCL) for machinery fault detection

The SKF® CMPT DCL is a digital alarm and display module. It is used as part of a machinery fault detection system to monitor analog signals from the SKF CMPT CTU vibration transmitter, various thermocouples and Resistive Temperature Detectors (RTD).

The DCL is a single channel module with digital display and alarm function with LED event lamp and relay contacts. The front panel digital display gives the user a visual indication of the monitored signal. The display can be scaled to indicate vibration (gE, g, mm/s, inch/s), temperature (°C, °F), etc.

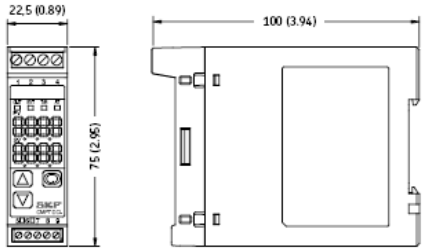
The DCL has programmable alarm and relay functions for remote control/indication of an alarm event and has a variable time delay. The DCL can indicate High, Low, High-Low, and various other alarm limits. The front panel event lamp illuminates (red) to indicate alarm. The relay contacts are programmable with various options (Normally Open/Normally Close, Non-latching/latching).

The DCL provides a 4 to 20 mA output signal proportional to the scaled analog input signal.

Two CMPT DCL modules are needed for standalone monitoring of a SKF CMPT CTU vibration transmitter (one each for vibration and temperature). One CMPT CTU and two DCL modules are together a user-friendly fault detection system of machinery vibration and temperature. The CMPT CTU transmitter can also be connected directly to the PLC/DCS automation system without the DCL modules.

Features

- Monitors various inputs
  - Current (mA)
  - DC voltage (i.e. vibration or temperature signals from CMPT CTU)
  - Thermocouple
  - RTD
- Digital LED display of monitored signals
- Programmable alarm function (one channel)
  - Alarm on High, Low or High-Low signal input, etc.
  - Front panel LED event lamp
  - Relay contacts
    - Normally Open or Normally Closed
    - Latching or Non-latching
  - Time delay (0 to 9999 seconds)
- Analog output signal (4 to 20 mA)
- Front panel user configurable
  - Input type
  - Display scaling
  - Alarm function
  - Analog output scaling
- No need for voltmeter and screw driver to set alarm function
- 35 mm DIN rail mounted



mm (inch)

Specifications

Power requirements

Supply Voltage: 24 V AC/DC (20 to 28 V AC/DC)

Supply current: 200 mA, maximum
Power: 6 W, maximum

Sensor input

Current ①: 4 to 20 mA, 0 to 20 mA
(Input impedance: 50 Ohm)

Voltage: 0 to 10 V DC; 0 to 1 V DC; 0 to 5 V DC; 1 to 5 V DC
(Input impedance > 100 kΩ)

Thermocouple: K, J, R, S, B, E, T, N, PL-II, C (W/Re5-26)
(100 Ω wire resistance or less)

RTD: Pt100, JPt100 three-wire system
(10 Ω or less per wire)

① 50 Ω shunt resistor required at input terminals (not included)

Alarm function

LED event lamp on front display (red)
Relay contact: 48 V DC/AC; 1 A max.
Programmable:
- Alarm setting value
- Optional alarm on High limit, Low limit, High-Low limit, High-Low range limit
- Optional Normally Open or Normally Closed relay contacts
- Optional Latching or Non-latching relay contacts
- Variable time delay (0 to 9999 seconds)

Output

Output signal: 4 to 20 mA, proportional to scaled input

Digital display

LED: Four red; H/7.4 mm x W/4 mm
Scaleable for: - Vibration (gE, g, mm/s, inch/s),
- temperature (°C, °F)
- etc.

Environment

Operating temperature: -10 °C to 50 °C (14 °F to 122 °F)
Storage temperature: -25 °C to 65 °C (-13 °F to 149 °F)
Humidity: 85% maximum
IP rating: 30

Mechanical

Weight: 0.12 kg (0.27 lbs)
Enclosure: Polyethylene and PET resin
Color: Gray with green terminals
Connectors: One 4–pole screw clamp
One 5-pole screw clamp
Wiring:
- Power and analog output 0.2 mm to 1.5 mm diameter (0.008 inch to 0.06 inch)
- Input and relay out 0.2 mm to 0.5 mm diameter (0.008 inch to 0.03 inch)

Mounting: 35 mm DIN-rail type EN50022
Dimensions: H/75mm x W/22.5mm x D/100mm
(2.95 inch x 0.89 inch x 3.94 inch)
Approval: CE

See the CMPT DCL Installation Manual for programming information and additional details for the interface with sensors, CMPT CTU, power supply, etc.

See www.skf.com for more information.

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SKF Copperhead Transmitter Unit (CMPT CTU) for machinery fault detection

The SKF® CMPT Copperhead Transmitter Unit (CTU) is a digital vibration and temperature transmitter. It can be used as part of a machinery fault detection system. The CTU can make three types of vibration signal process analysis — SKF Acceleration Enveloping (gE), acceleration (g), or velocity (mm/s or inch/s). The type of vibration analysis is user selectable. The CTU has analog output signals proportional to the processed vibration and temperature for connection to automation systems and SKF CMPT DCL monitors. The CTU can process vibration signals from the SKF CMPT family of sensors or other industrial accelerometers.

- SKF Acceleration Enveloping vibration analysis is useful to identify repetitive impact type vibrations generated by machinery faults due to loose components, gear faults, lack of lubrication and rolling bearing damage.
- The acceleration vibration analysis is useful to monitor overall machinery and structural vibration, including machinery having journal bearings.
- The velocity vibration analysis is useful to identify overall machinery vibration levels such as looseness and unbalance and including machinery support by journal bearings.

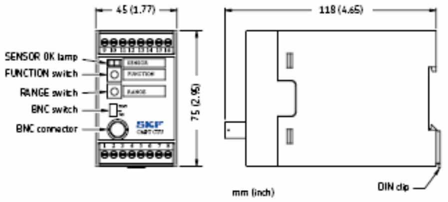
The CMPT CTU has unique features to monitor both normal speed and low speed machinery (n < 40 r/min).

Features

- Suitable with accelerometer sensors (10 mV/g to 230 mV/g)
- Temperature converter for accelerometers with integral temperature sensors
- Three user selectable vibration signal process analyses①:
  - SKF Acceleration Enveloping, gE (ENV3)
  - Acceleration, g
  - Velocity, mm/s (inch/s)
- Front panel user configurable for:
  - Vibration
  - Output range
  - Optional sensor input or buffered vibration output input
  - Optional signal decay for Acceleration Enveloping Peak hold
  - Optional output signal averaging
- Analog output signals – Processed vibration and temperature for interface with PLC/DCS and CMPT DCL alarm/display monitors
- 35 mm DIN rail mounted with rugged steel retainer clip
- Front panel mounted BNC connector for buffered vibration and temperature measurements
- Front panel sensor OK / overload lamp for detection of sensor and CTU faults
- CAN-bus interface for connectivity of multiple numbers of CTU and remote monitoring via computer
- Internal isolated DC/DC converter for grounding loop and reverse polarity protection
- Auxiliary 24 V DC voltage output for optional powering of other sensor types (tachometer).

① Only Acceleration Enveloping (ENV3). Acceleration (RMS and Peak Hold), and Velocity ISO are enabled on initial CPHD CTU modules.

SKF



Specifications

Power requirements

Supply Voltage: +24 V DC (22 to 28 V DC)

Supply current: 250 mA, maximum

Power: 6 W, maximum

Sensor Input: Vibration - Constant current source accelerometer (10, 30, 100, 230 mV/g)

Optional Temperature (10 mV/ °C)

Vibration process analysis ①

Acceleration Enveloping, gE (ENV3): 500 Hz – 10 kHz

Acceleration, g: 2 Hz – 20 kHz (RMS and Peak Hold)

Velocity, mm/s (inch/s), ISO: 10 Hz – 1 kHz

① Only Acceleration Enveloping (ENV3), Acceleration (RMS and Peak Hold), and Velocity ISO are enabled on initial CPHD CTU modules.

Vibration signal decay: 1 second or 10 seconds (SKF acceleration Enveloping only)

Output

Processed vibration: 4 to 20 mA / 0 to 10 V DC proportional to full scale vibration

Temperature: 4 to 20 mA / 0 to 10 V DC proportional to 0 to 120 °C

Buffered acceleration output: BNC connector, screw terminals

Output Range: Full scale @ 100mV/g sensor

	Accel Env, gE and Accel, g	Velocity ISO-RMS, mm/s (PEAK inch/s)
Range 0	3	1,5 (0.075)
Range 1	10	5,0 (0.25)
Range 2	30	15,0 (0.75)
Range 3	100	50,0 (2.5)

Output averaging: On / Off

CAN-bus: SKF protocol (see SKF for details)

Auxiliary power: 24 V DC / 20 mA maximum

Environmental

Operating temperature: 0 °C to 70 °C (32 °F to 160 °F)

Storage temperature: -40 °C to 85 °C (-40 °F to 185 °F)

Humidity: 95% maximum

IP rating: IP20

Mechanical

Weight: 0,225 kg (0.102 lbs)

Enclosure: Thermoplastic ABS

Color: Gray

Connectors: two 8-pole pluggable screw clamp type (16 total)

Wiring: 0,2 mm to 2,5 mm (24 to 12 AWG)

Mounting: 35 mm DIN-rail type EN50022 with steel retaining clip

Dimensions: H/75 mm x W/45 mm x D/118 mm (2.95 inch x 1.77 inch x 4.65 inch)

Approval: CE

General application recommendations

	Application conditions	
	Normal speed machinery	Low speed machinery (< 40 r/min)
Sensor	CMPT 2310 or CMPT 2310T	CMPT 2323 or CMPT 2323T
CMPT CTU settings		
- Output range	1, 2 or 3	0 or 1
- Vibration signal decay	1 second	10 seconds

See the CMPT CTU Installation Manual for additional details for the interface with sensors, power supply and monitoring devices. Tables are provided for use with 10, 30, 100, 230 mV/g sensitivity sensors. The CTU should be mounted within 100 m (330 feet) of the accelerometer sensors.

See www.skf.com for more information.

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