University of Southern Queensland

Faculty of Health, Engineering & Sciences

Investigation of Shunt Vehicle Derailments

A dissertation submitted by

Chris Langes

In the fulfilment of the requirements of

ENG4112 Research Project

Towards the degree of

Bachelor of Engineering (Mechanical)

24 October 2013

ABSTRACT

The Aurizon (formerly QR National) Workshops in Rockhampton is a large rail heavy maintenance facility where the primary function is to repair and modify rollingstock. As the workshops are in close proximity to the Central Queensland coal fields most of the rollingstock presented are coal wagons and locomotives. Due to the fact that most of the rollingstock in the workshop yard is unpowered an external power source in the form of a rail mounted shunt vehicle is used to place the rollingstock in the desired location. The site has two shunt vehicles, a DN 300 and a DN 100. Both vehicles are designed for on road and on track operation. The on track operation is facilitated by the rubber road tyres contacting the track to provide traction with the on track guidance provided by hi-rail wheels front and rear.

Both machines have derailed during normal operations heightening the risk of possible injury as well as causing major disruptions to production as the machine is quarantined for investigation following a derailment. Management are therefore very keen to try and establish a root cause of these derailments. The focus of this preliminary report is to provide an update on the investigations into the root causes of these derailments.

University of Southern Queensland

Faculty of Health, Engineering & Sciences

ENG4111 & ENG4112 *Research Project*

Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in this dissertation are entirely my own efforts, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specially stated.

Christopher Brian Langes

Student Number: 0061012339

....
Signature

24/10/2013
....
Date

Acknowledgements

This project was conducted under the principal supervision of Dr Jayantha Epaarachchi, Faculty of Engineering and Surveying, University of Southern Queensland.

I would also like to acknowledge and thank the Engineering staff and the Rollingstock Maintenance staff at the Rockhampton Rollingstock Maintenance facility for their continued support, mentoring and assistance.

Chris Langes

Contents

List of figures

List of Tables

Glossary

RISSB	Rail Industry Safety and Standards Board
NARCOA	North American Railcar Operators Association
AAR	Association of American Railroads
μ	coefficient of friction
α	Yaw angle
V_t	Lateral velocity of a wheelset
ω	Angular velocity
r	rolling radius
ψ	Wheelset angle of attack
β	Wheel flange angle
L	lateral force at wheel flange
V	Vertical load on the wheel
N	Force normal to flange angle

Chapter 1 - INTRODUCTION

What is a derailment?

Standard 1 – Guideline for the Top Event Classification of Notifiable Occurrences

- Where one or more rollingstock wheels leave the rail or track during railway operations

AS/RISSB – 7519:2008 – Railway Rollingstock – Bogie Structural Requirements

- An incident in which one or more wheelsets run off the track

Figure 1-1: Derailment

1.1 Project Objectives

The aim of this project is to conduct an investigation into the causes of the derailment of the D&N shunt vehicles whilst under normal operation within the Aurizon (formerly QR National) Rockhampton workshops yard. Based upon the outcomes of the investigation recommendations will be made to eliminate/ minimise D&N shunt vehicle derailments. The project objectives are:

1. To describe the general operation of the D&N shunt vehicles during shunting operations at the Aurizon Rockhampton Rollingstock maintenance facility.
2. Research the requirements for safe on track operation of a vehicle.
3. Fit monitoring equipment to the D&N shunt vehicles to collect operational data.
4. Evaluate and analyse the data collected.
5. Provide recommendations
6. Submit an academic dissertation on the engineering research undertaken.

1.2 Background

The Aurizon Rockhampton Rollingstock Maintenance facility is a heavy repair workshop that is capable of carrying out repairs and modifications to locomotives, wagons and track vehicles. The workshops cover 3 hectares with the heavy lift sheds connected by rail lines as can be seen in Figure 1-2.

Figure 1-2: Workshop layout

All rollingstock brought into workshops for repair or modification have no means of self-propulsion and therefore require an external power source to move them on site. This is achieved with the use of a shunt vehicle, commonly called a shunter; the shunter also provides the braking force. The Rockhampton Aurizon workshops have two shunters, the DN 300 and the DN 100. Both shunters have couplers at the front and the rear so are capable of pushing and towing connected loads. The shunt vehicle is connected to the rollingstock via an automatic coupler on the rollingstock that requires manual release when disconnection is required.

1.3 Reliability issues

Both the DN 100 and DN 300 have a history of derailing in service. Prior to changes to Aurizon’s Safety Management System these derailments were an inconvenience and the vehicle was re-railed and the operations resumed. Now, Aurizon’s Safety Management System requires all derailments are to be reported and an investigation carried out to try and determine the root cause of the derailment. The derailments have occurred when operated as a single vehicle and also when shunting rollingstock.

Following a derailment the shunter is ‘tagged out’ and the shunt team are stood down pending a drug and alcohol test. An investigation into the cause of the derailment is initiated as soon as practical after the incident. The non-availability of the shunter after derailment impacts heavily on workshop production as rollingstock cannot be placed as required. There is also an increasing dissatisfaction among the operators with the shunter’s numerous derailments. The union convenor that represents the shunt operators has advised there maybe industrial action if the derailment issue cannot be resolved.

Chapter 2 - LITERATURE REVIEW

2.1 The D & N Shunters

The D & N Shunters, models DN 100 and DN 300, are a rubber tyred articulated steer purpose built tractors suitable for both on rail or off rail travel. For on track operation small diameter hi-rail wheels are lowered to engage the track and provide guidance on track whilst the rubber tyres provide vehicle support and traction. The vehicles rated shunting capacities are, 300 tonnes on rail for the Model DN-300 and 100 tonnes for the Model DN-100; subject to reductions for speed, weather conditions and grades. The D & N Shunters can be registered for on road travel and can be operated on the rail or road at speeds up to 30 kph. The DN 100 and DN 300 are illustrated below with the specifications for the two machines given in Table 2-1.

Figure 2-1: DN 300

Figure 2-2: DN 100

When driving on road the hi-rail wheels front and rear are lifted and held in the raised position. When on rail operation is required the machine is driven to a suitable level crossing and the machine is aligned with the rails. The front hi-rail wheels are lowered to ensure flanges are engaged between the rails. The machine is then driven forward to ensure the rear hi-rail wheels are above the rail and then they are lowered ensuring the flanges are engaged between the rails. The steering lock out is switched to lock so there is no articulation in the vehicle and the machine is ready for on rail use. During on rail operation the machine operates in four wheel drive.

Table 2-1: D&N Shunter Specifications

Specifications		
	DN 300	**DN 100**
Tyres	R295 x 22.5 x 12 ply	300 x 15
Weight –		
Front axle	7500 kg	2750 kg
Rear axle	7500 kg	2750 kg
Dimensions –		
Overall length	6500mm	5000mm
Overall width	1800mm	1600mm
Overall height	2650mm	2500mm
Wheel base	3000mm	2100mm
Turning radius (outside)	4200mm	3800mm
Date commissioned	March 2001	March 1998

The tyres specified in the operator's manual for the DN300 appear to be incorrect as the tyres presently fitted to the vehicle are 385 R22.5. The Michelin Tyre Company advise the specified tyre, R295 x 22.5, does not have sufficient load rating for the axle loads whereas the tyres fitted presently do. A check of the maintenance records since the commissioning of the DN 300 shows there have been numerous tyre changes but no sizes are listed. However, the maintenance fitter responsible for the maintenance of the DN shunter believes a spare tyre on site, the same size as fitted, is an original spare. The tyres fitted to the DN100 are as per the specifications.

2.2 Wheel – Rail Contact theory

The basic principal of wheel – rail system is flanged wheelset rolling along a rigid steel track and because the track is rigid the wheelset has only the degrees of freedom as illustrated in figure 2.3:

- Lateral displacement (*Y*) and,
- Yaw angle, (α)

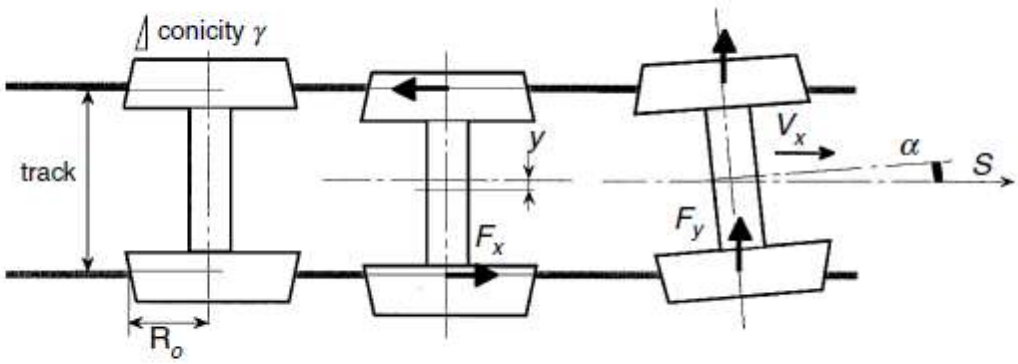


Figure 2-3: Wheelset degrees of freedom (Ayasse & Chollet 2006)

A railway wheelset can be described as two conical, nearly cylindrical wheels, linked together with a rigid axle. Each wheel has a flange on the track centre line side of the wheel so as to prevent derailment. In a straight line the flanges are not in contact with the rail head, but the rigid link between the two wheels suggests that the railway wheelset is designed to go straight ahead, and will go to flange contact with the rail head only in curves. This is the railway dicone or wheelset. (Ayasse and

Chollet 2006). In order to have the wheelset negotiate curves the tread profile of the wheelset has a slight taper from the flange to the outside of the wheel; the largest wheel tread diameter is closest to the flange. In cornering the wheelset will have the flange of one wheel forced into contact with the rail and the other wheel on the axle will then run on the outer section of the tread; effectively the wheelset will be running with wheels of different diameters, therefore assisting curve negotiation.

During normal operation the interface between the wheel and the rail is a small horizontal contact patch subjected to high stresses. Wheel –rail contact is extremely complex and a full explanation is beyond the scope of this report. For further information the reader is advised to refer to the Handbook of Railway Vehicle Dynamics.

Although the hi-rail wheels have a conical taper as described above the two wheels are not fixed on the axle; the axle in this case is fixed and the wheels rotate about the axle. When cornering the flange of the wheel on the outer curve makes contact with the rail as described above. The two wheel velocities in a curve are therefore independent of each other. This can result in flange climb issues and is covered in Section 2.5.

2.3 Derailment

According to the RISSB Derailment Investigation and Analysis Guideline there are many causes of derailment; these can be:-

- Wheel(s) lifted off the rail,
- Rail gauge widening,
- Wheel obstruction,
- Wheels rotate over rail,
- Flange climb.

The above derailment mechanisms can be summarised as:

- Wheels lifted off the rails – large forces or shocks in the train (rapid acceleration or braking), or collapse of a safety critical part of the vehicle.

- Rail gauge widening – this requires failure of the rail or the rail fastening/support, or the wheel moving on the axle.
- Wheel obstruction – a physical obstruction of the wheels or bogie by relatively small objects e.g. ballast or dislodged rollingstock components. Wheels are deflected from the rails or the bogie is lifted.
- Wheels rotate over the rail – this is associated with overturning of the vehicle (rollover). The most common cause being excessive speed on a tight curve.
- Flange climb – a change in the train forces and conditions at the wheel flange/rail contact point that leads to the flange climbing and crossing the rail.

Wu and Wilson 2006 state flange climb derailments generally occur on curves. The wheels on the outer rail usually experience a base level of lateral force to vertical force ratio (L/V) that is mainly related to:

- Curve radius,
- Wheel profile,
- Bogie suspension characteristics,
- Vehicle speed.

These factors combine to generate a base wheelset angle of attack (ψ), which in turn generates the base level of lateral curving force. It is when the L/V ratio exceeds the capabilities of the wheel, flange climb occurs.

In addition to the derailment mechanisms listed above Tyrell, Weinstock and Greif in a report for the US Department of Transportation state that track twist can lead to derailment for torsionally stiff vehicles. Track twist is the difference in cross level between two points on the track. The report states a flange climb derailment can occur in a curve if the track is twisted which is consistent with Wu and Wilson 2006 above. A derailment due to track twist in a curve can happen because the track twist causes the vertical downward forces on the front wheels on one side of the wagon and the opposite side rear wheels to reduce. To steer through a curve there must be lateral forces on the flanges and if the unloading of the vertical forces is greater than what is necessary to overcome the lateral forces the flange will climb the rail.

Evaluation of the above derailment mechanisms as a possible derailment cause for the shunt vehicles reveals the most likely cause is that of flange climb. This is based on the fact that sections of track where derailments have occurred have been checked for twist and the results indicate that there is less that 5mm of twist in a 30 metre section. With the hydraulic system supplying the lift rams being constant pressure and with the relatively slow speed of the shunt any deviation in the track should not result in a loss of vertical force on the hi-rail wheels; the hydraulic ram should adjust keeping the downward force constant. The other mechanisms are unlikely to cause derailment of the shunter, but should not be discounted.

2.4 Flange Climb Process

The lateral velocity of a wheel due to its rotational velocity is given by

$$V_t = -\omega r \sin(\psi)$$

where V_t is the lateral velocity of the wheelset, r is rolling radius and ψ is wheelset angle of attack. (This angle is the same as the Yaw angle (α – Fig 2.3), but is more commonly referred to as the wheelset angle of attack).

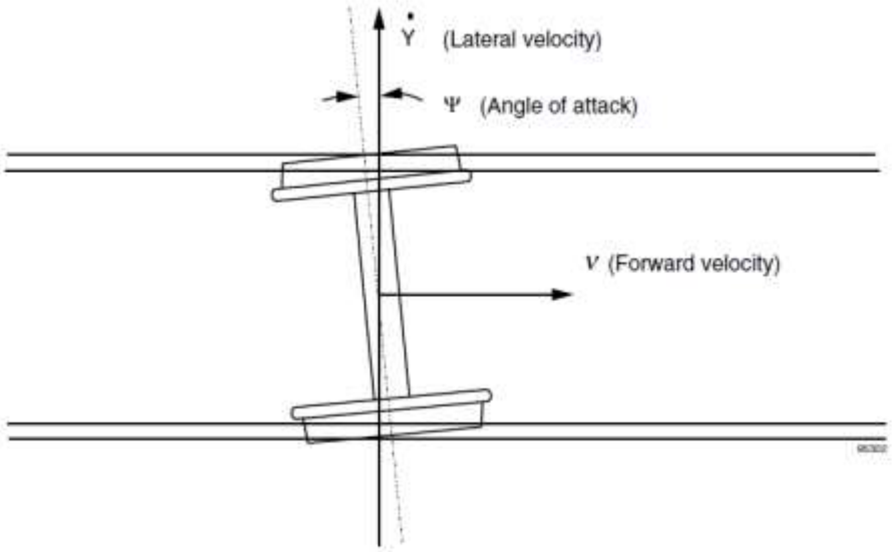


Figure 2-4: Wheelset angle of attack (Wu & Wilson 2006)

When a wheel is rotating there are a number of forces generated that influence the wheel. Lateral creepage is influenced by the angle of attack through a component of the wheelset's rotational velocity. If there is lateral velocity in addition to the velocity set up by the wheels rotational velocity the net lateral velocity is given by:

$$V_y = y - \omega r \psi$$

Lateral creepage can be defined as the wheel –rail relative lateral velocity divided by the forward velocity.

$$\gamma_y = (\psi - \left(\frac{\dot{y}}{V}\right) sec\delta)$$

where $\left(\psi - \left(\frac{\dot{y}}{V}\right)\right)$ is the effective angle of attack and is a function of the wheelsets lateral velocity. As the term sec(δ) always has a positive value during flange climb, the direction of the lateral creepage is dependent on the sign of the term $\left(\psi - \left(\frac{\dot{y}}{V}\right)\right)$. The lateral creepage equals zero when ψ equals $\frac{\dot{y}}{V}$. The lateral creepage changes direction when $\psi < \frac{\dot{y}}{V}$. The spin creepage also affects the lateral creep force. The direction of the lateral creep force depends on the resultant of the contribution of both the lateral and the spin creepages.

Wu and Wilson state the flange climb process maybe illustrated in three phases as illustrated in Figure 2.5.

The first phase, left hand illustration, the wheel is under a lateral force and the wheel moves right initiating flange contact with the rail. A lateral creep force is produced and acts on the wheel to oppose flange climb. The second phase the flange contact angle is increased and the wheelset lateral velocity decreases. This results in the lateral creepage and creep force reversing direction due to the change of sign of the effective angle of attack; the lateral force is assisting the wheel to climb. Once the maximum contact angle has passed, the wheelset lateral velocity increases resulting in rapid lateral displacement of the wheelset. This results in the effective angle of attack approaching zero and changes sign. This leads to the lateral creepage and creep force changing direction and the lateral creep forces now oppose the wheel climbing motion, as shown in phase 3.

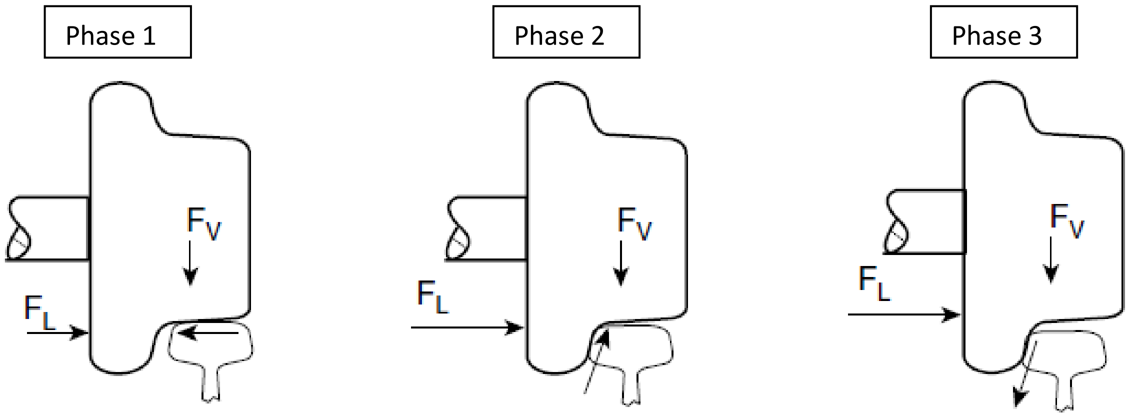


Figure 2-5: Flange climb process (Wu & Wilson 2006)

2.5 Nadal's Theory of Flange Climb

Nadal in 1896 proposed the Nadal equation for flange climb and is the most commonly used limiting derailment quotient (L/V ratio) for incipient wheel flange climb derailment. The equation defines the derailment quotient in terms of just two variables, wheel flange angle, and the wheel – rail interface friction coefficient (Williams W 2012, 'Derailment *quotient sensitivity to angle of attack – applying the method of Yokose'* Conference of Railway Engineering, Brisbane Australia pp. 501-510).

Nadal assumed the wheel was initially in two point contact with the flange point leading the tread point. He concluded that the wheel material at flange contact point was moving downwards relative to the rail material, due to the wheel rolling about the tread contact. Nadal further theorised that wheel climb occurs when the downward motion ceases with the friction saturated at the contact point (Wu and Wilson).

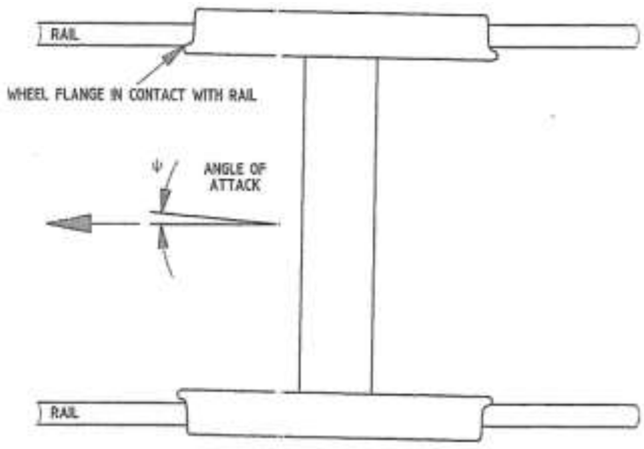


Figure 2-6: Flange contact with wheelset angle of attack (RISSB 2013)

Flange contact point and angle of attack are illustrated in Figures 2.6 and 2.7.

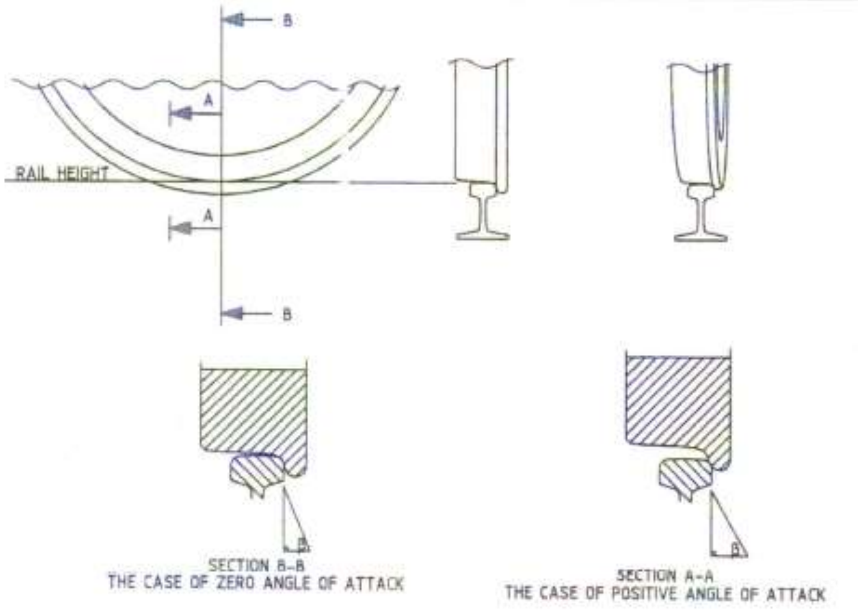


Figure 2-7: Wheelset angle of attack (Wu & Wilson 2006)

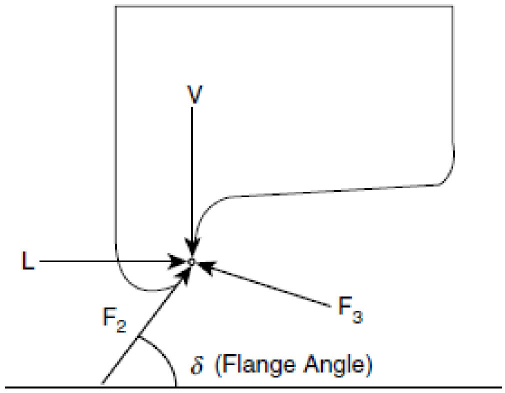


Figure 2-8: Forces at flange contact location

Using the equilibrium of the forces shown in Figure 2.8 in conjunction of Nadal's assumption the following equations can be developed:

$$F3 = V\left(cos\beta + \left(\frac{L}{V}\right) sin\beta\right)$$

$$F2 = V\left(sin\beta - \left(\frac{L}{V}\right) cos\beta\right) when\ (Vsin\beta - Lcos\beta) < \mu * F3$$

$$F2 = \mu * F3 \qquad\qquad when\ (Vsin\beta - Lcos\beta) \geq \mu * F3$$

The above equations can be expressed as the L/V ratio:

$$\frac{L}{V} = \left\{\frac{tan\beta - \left(\frac{F2}{F3}\right)}{1 + \left(\frac{F2}{F3}\right) tan\beta}\right\}$$

For friction saturation where F2/F3 = μ, the following equation in figure 2.9 results:

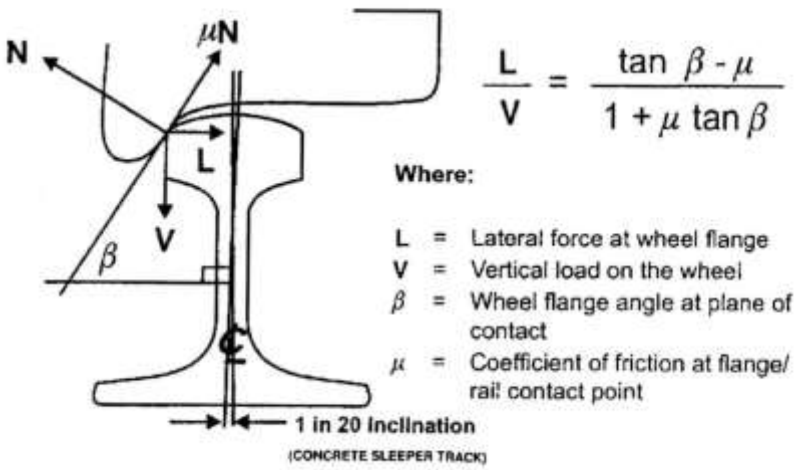


Figure 2-9: Flange climb components (RISSB 2013)

If the L/V critical ratio is exceeded by the actual conditions there is a very strong possibility of flange climb. The two most likely reasons for this occurring are a reduction in wheel load or an increase in lateral force. The flange angle and the coefficient of friction can also contribute to an increase in derailment risk. A change of flange angle can occur as wheels wear in service but regular maintenance checks are able to detect when a flange is no longer serviceable. The coefficient of friction however is not so easy to determine. Tyrell, Weinstock and Greif state that friction coefficients between the wheel and the rail higher than 0.5 have been observed during field trials. This is slightly higher than the 0.35 – 0.45 stated in the RISSB Derailment Investigation and Analysis Guideline. Both sources agree that rain greatly reduces the friction between the wheel and rail.

Nadal criterion assumes when the critical L/V ratio has been exceeded the derailment is instantaneous. Wu and Wilson report that both field tests and simulations prove that wheel flange climb derailments would only occur when the L/V ratio limit has been exceeded for a certain distance limit or time duration limit. The AAR Mechanical Division, Manual of Standards and Recommended Practices, Section C-Part II, Volume 1, Chapter XI, Section 11.5.2 states that the individual wheel L/V should not exceed 1.0 on any wheels measured and the instantaneous sum of absolute wheel L/V's on any axle shall not exceed 1.5. The values are not to exceed indicated value for a period greater than 50 msec per exceedence.

2.6 Flange climb of independently rotating wheels

As previously stated a railway wheelset is comprised of two wheels mounted on a solid axle and therefore both wheels must rotate at the same speed. The tapers on the wheels assist the wheelset negotiate curves due to the fact the wheelset shifts sideways on the rail resulting in two different diameters rolling on the track. Longitudinal creep forces are produced that form a moment to steer a bogie around a curve. Flange climb studies (Wu and Wilson) have indicated that as the ratio of longitudinal force to vertical force increases, the wheel L/V ratio required for derailment also increases. Therefore the Nadal flange climb criterion can be relaxed based on the level of longitudinal force and the flange climb would occur at an L/V ratio above the Nadal limiting value in the presence of longitudinal force.

Because independently rotating wheels can rotate at different speeds there are no longitudinal forces producing a steering moment. This can lead to higher wheelset angle of attack, higher lateral forces, higher L/V ratios and increases wheel and rail wear. In addition, since there are no longitudinal forces the wheel-rail friction acts entirely in the lateral direction, resulting in the shortest distance to climb and a greater flange climb risk. Therefore independently rotating wheels have less tolerance to track irregularities that may suddenly increase wheel lateral force or reduce vertical forces.

In summary, Wu and Wilson state, vehicles with independently rotating wheels need to be carefully designed to control flange climb and wheel wear. Additional control mechanisms, such as linkage or active control systems, can be used to steer the wheelset on curves and track perturbations. Without such control mechanisms, the wheel-rail profiles, vehicle track maintenance and wheel-rail friction will need to be more strictly controlled and monitored to prevent wheel flange climb.

2.7 Track lubrication

Friction between the wheel and the rail is a significant factor in the wheel-rail interface; it is both desirable and undesirable depending on the circumstances. Friction is required for wheel adhesion for movement on the rail as well as for providing the braking force and therefore is desirable. Friction in the form of wear, noise generation and in the wheel-rail interface in curves is undesirable, and where possible efforts should be made to lower the value. In simple terms a higher coefficient of friction is required for traction and a lower coefficient of friction is required to reduce wheel wear and assist in cornering. Olofsson and Telliskivi compared coefficients of friction measured on track and in the laboratory. For pure nonlubricated sliding tests the level was roughly the same, varying between 0.5 and 0.6, agreeing with the results reported by Weinstock. For a full scale lubricated rail the coefficient of friction was lowered and varied between 0.2 and 0.4. These lower coefficients of friction are desirable at the wheel-rail interface when a wheelset is negotiating a curve as the flange is in contact with the rail head.

Reducing the friction between the wheel-rail interface can be achieved with friction modifiers either in solid or liquid form. Lewis and Dwyer-Joyce state the main difference between the two modifiers is the application thickness. Solid lubricants will provide a film thickness of 10-30µm and liquid lubricants in the form of grease provide a film thickness of less than 5µm.

2.8 Twist test

As can be seen from the information above wheel unloading can be a contributing factor to derailment. To assess the wheel unloading performance and underframe behaviour of rollingstock on a track geometry that replicates the twist conditions that could occur on a Railway Network a static twist test is performed. All rollingstock must pass the static twist test before registration to operate on track is given. The twist test is intended to evaluate the capability of rollingstock to accommodate track twist without unacceptable reductions in the wheel load at rail. High twist is found in the transitions leading into and out of curves, but may occur anywhere in the track. During the static twist test the rollingstock is simulated to be travelling down a Cant Ramp that included an unintended dip that is superimposed on the Cant Ramp as can be seen in Figure 2.10.

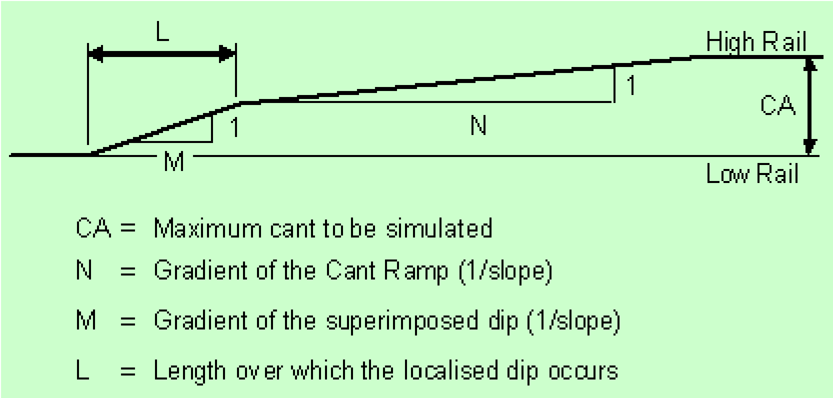


Figure 2-10: Track shape for twist test

To achieve the required track shape for the twist test the rollingstock is placed on blocks of a predetermined height. The heights of the jacking blocks are calculated using the rollingstock wheelbase dimensions and equations 2 & 3 from Section 6.3.2 and Table A2 of AS 7509.2 shown in Figures 2.11 and 2.12 below.

On local dip

$$P = B / M$$

P = Jacking Height of wheel (mm)
B = Horizontal distance to a wheelset from first wheelset (mm)
M = Parameter defining the gradient of the localised dip (1/slope)

EQUATION 2 - WHEEL JACKING HEIGHT WHEN ON LOCAL DIP

Figure 2-11: Equation 2 wheel jacking height when on local dip

On cant ramp

$$P = H + (B - L) / N$$

P = Jacking Height of wheel (mm)
H = Height at end of local dip/start of cant ramp (mm)
B = Horizontal distance to a wheelset from first wheelset (mm)
L = Length over which the localised dip occurs (mm)
N = Parameter defining the gradient of the Cant Ramp (1/slope)
CA = Maximum cant to be simulated (mm)

EQUATION 3 - WHEEL JACKING HEIGHT WHEN ON CANT RAMP

Figure 2-12: Equation 3 Wheel jacking when on a cant ramp

Track Manager	Route	Local Dip				Cant Ramp	
		L (mm)	D (mm)	M	H (mm)	N	CA (mm)
ARTC	Interstate Standard Gauge Network	4000	24	100	40	250	No limit
RailCorp		4000	24	100	40	250	No limit
AustralAsia Network		4000	24	100	40	250	No limit
V/Line	Victoria 1600mm gauge	4000	24	100	40	250	No limit
QR	Brisbane-Townsville, Townsville-Mt Isa,	3000	20	100	30	300	105
	Goonyella, Blackwater, Moura, Brisbane Suburban Area	3000	25	92.3	32.5	400	105
	Category 7 to 10 lines	3000	30	80	37.5	400	105
PTA of WA	Perth suburban (1067mm gauge)	2000	6.6	133.3	15	237.3	54

Figure 2-13: AS 7509.2 Table A2 Track twist shape parameters

Jacking height calculations

DN 300 wheel base dimensions

- Between drive axles (rubber tyres) – 2800mm
- Between hi-rail axles (steel wheels) – 4360mm

Wheel on a local dip – Equation 2

- Wheel 2 = 780/80 =9.75mm **(10mm)**

Wheels on cant ramp – Equation 3

- Wheel 3 = 37.5 + (3580-3000)/400 = 38.95mm **(39mm)**
- Wheel 4 = 37.5 +(4360-3000)/400 = 40.9mm **(41mm)**

Allowable wheel unloading

The maximum allowable wheel unloading is 60% and is calculated by firstly determining the average wheel load, and

$$\text{Average wheel load} = (W_{left} + W_{right})/2 \qquad (1)$$

Wheel unloading

$$\text{Wheel unloading} = 1 - (\text{minimum wheel load}/\text{average wheel load}) \qquad (2)$$

2.9 Other industry experiences

The manufacturers of the DN shunt vehicles sold the business and enquiries were made with the new owners, Varley, to see if there were records on how many shunt vehicles were made and where these vehicles were placed into service. Unfortunately there are only limited records and it appears there may have only been two DN 300 vehicles manufactured; one was sold to Aurizon for operation in Rockhampton and the other, if manufactured went to a national logistics company. This company was contacted but there are no records of the company purchasing or operating a DN 300. It is therefore assumed there was only ever one DN 300 manufactured. There were 15 DN 100 vehicles manufactured. Varley advised most of the DN 100 shunt vehicles were sold to Queensland Rail. An Aurizon facility where DN 100 shunt vehicles are still in operation report there have been no reported derailment issues involving these vehicles. This could be due to the fact that at this facility the shunters do not have to negotiate tight curves; most runs are along straight sections of track.

Several other rail maintenance facilities within Australia and New Zealand were contacted to determine what types of shunt vehicles are used in their operations and if any derailment issues had occurred. No other rail maintenance facility contacted operates the DN type shunters; most operate shunters such as the Trakmaster where the hi-rail wheels provide the guidance and traction. One operator using these machines did report that derails did occur when towing a heavy load. This occurred mainly when the rollingstock had couplers that were stiff and did not easily slide during cornering thereby increasing the lateral force on the shunters hi-rail wheels. An external operator using a Linmac shunter reports this machine regularly derails. The Linmac is similar to the DN shunter in that the road tyres contact the rail to provide traction and hi-rail wheel provide on track guidance but the hi-rail set up is slightly different. The downward force on the Linmac's hi-rail wheels has to be manually adjusted; the hydraulic rams do not adjust in service as those on the DN shunters. The Linmac operator reports no investigations have been carried out by the operator to determine the cause/s of the derailments.

NARCOA, the North American Railcar Operators Association hi-rail vehicle purchasing and operating guidelines, version 1.0 August 20, 2001, report grade crossings and turnouts present hazards to hi-rail vehicles due to the highway tyres ride up high on the pavement causing the hi-rail guidance wheels to lift off the track. The Operators Association advise if the road tyres on the machine are too wide the guide wheel lift off problem will occur more frequently. The association states that at some stage during the vehicle's operation a hi-rail vehicle is going to derail, but if it is operating at a prudent speed there should be no substantial damage and the vehicle can be re-railed. The re-railing task is made easier if the road tyres on the vehicle are a narrower stiff walled tyre.

Hi-rail wheel systems allow conventional road vehicle to be driven on a rail way track. Searches have revealed there have been many patents registered for hi-rail wheel systems. Patent number 3,020,858, filed in October 1957 was for the adaption of hi-rail wheels to a vehicle so as it could be driven on road as well as track as vehicle only; there was no provision for coupling to other rail mounted equipment. Patent number 3,638,579 filed in November 1969 was for a convertible rail-highway shunting locomotive, basically a tractor with hi-rail wheels fitted front and rear. The patent title is somewhat misleading as the patent covers the design of the coupler on the rear of the tractor that couples to rail rollingstock. The main objective of this design was to reduce the lateral displacement of the traction wheels in a curve and thereby reduce the thrust forces on the hi-rail guide wheels. In October 2001 patent number 6,298,792, Hi-Rail Wheel Assembly for Improved Traction provided an adjustment system for the hi-rail wheels so as the rubber traction tyres worn down the downward force on the hi-rail wheels could be maintained.

2.10 Track specification

There are numerous track standards that make up Aurizon's Network Safety Management System and the tracks within the Rockhampton Workshops yard should conform to these standards if track condition is to be ruled out as a possible causal factor for the shunt tractor derailments. Many of the tracks within the workshop yard are on wooden sleepers and are showing signs of deterioration; however, many of the derailments have happen on recently new track constructed using concrete sleepers.

- CETS module 8 – Track Alignment

The module specifies the minimum requirements for design track gauges and states curves of radius <300 m and >160 m are to have a gauge of 1073mm. The limiting curvatures for existing yard tracks are 80 m. The maximum speed for a radius of curve ≥80 m and ≤100 is 25 km/h. Cant should not be applied on yard tracks, except where the speed exceed 15 km/h. It has been determined that several curves within the workshops yard are 60m radius and therefore do not conform to the standard. Although the track may not conform to the standard, Quotation request No. 60020741 for the supply, delivery, Testing and Commissioning of one Railway Shunt tractor for Hauling Queensland railway Rollingstock states the DN 300 is capable of negotiating 60 m radius curves.

- CETS module 2 – Rail

  The minimum rail size for axle loads (tonnes) >20 and ≤26 for a speed ≤25km/h is 41 kg/m for existing track.

2.11 Monitoring Equipment

2.11.1 Transducers

Linear

Research into linear transducers revealed there are many types available with varying specifications and costs. The OMRON ZX1 CMOS laser sensor was within the project budget and determined to be the most suitable transducer for mounting on the DN 300 shunter for the following reasons:

- Prewired with selection of cable lengths, 0.5m – 5m,
- Shock resistance – 500m/s^2 in x, y & z directions,
- Ambient temperature range – -10°C to 55°C,
- Resolution - 30µm.

Refer Appendix B for the complete ratings and specifications for the laser sensors.

Hydraulic

The hydraulic pressure to the hi-rail axle rams is set at 350 psi (24.13 bar) on the DN 100 and 400 psi (27.57 bar) on the DN 300. A pressure transducer of 0 to 35 bar range with 4 – 20mA output was chosen to be installed in the hydraulic line as the system operating pressure is around midrange of the transducer. The transducer has the capacity to handle an increase in pressure without failure should the hydraulic system experience an overpressure situation. Refer Appendix B for the transducer specifications.

2.11.2 Cameras

A TECHview 4 channel DVR, model QV-3028 with four colour CMOS cameras connected is capable of recording 123 hours of motion detection. The cameras were motion activated.

2.11.3 Labview instrumentation

The National Instruments Labview application for the data acquisition system is shown in Figures 2.14 and 2.15. The application was written in version 9 of the software. The hardware is a 4 channel, 9215A, USB, 4 channel, 16 bit, simultaneous sampling Data acquisition board. Refer to Appendix C.

Referring to Figure 2.14 - The sampling rate for the system is 16 Hz. This was set by configuring the sampling rate of the system to 2048 Hz, and taking the average over 128 samples. The accuracy of this system was observed, and checked, by displaying the raw data of all 4 channels in a graph (black graph in the top lhs of the front panel), then displaying the averaged data over 128 samples, for each channel in their own graph (blue graphs down the right hand side of the front panel). The stop button cancels the execution of the program and the Start/Stop recording button controls when the data is recorded to a file.

The block diagram shown in Figure 2.15 shows the waveform data being read by the DAQmx read block inside the while loop. This block reads the waveform data from the 9215A portable USB data acquisition device (refer Appendix B for details). The read block is set up with DAQmx create channel, DAQmx timing and DAQmx start task blocks outside the while loop which sets the timing, the number of channels and also transitions the application to the running state to begin the data sampling.

The output from the read block is an array of waveforms. To scale this information into data, the timing components of the waveform needs to be removed so that it can be scaled, for a calibrated display. This is accomplished using WDT index blocks which select individual waveforms from the array. These are numbered 0 – 3. Once the waveforms are indexed from the array, the timing components are removed using a "Get Waveform Components" block to attain the data for scaling into the appropriate units for display. The mean of 128 samples is calculated using a "Mean" block. This mean is then scaled into the appropriate units by passing it through a formula block that contains the equations for displaying the data into calibrated units.

For example the oil pressure switch (ch 3) has an input range from 0 bar – 35 bar. The corresponding output range is 4 mA – 20 mA. Passing this current through a 150 ohm resistor converts the current into a range from 0.6 V to 3 V. If we represent the voltage across the resistor by "g" and represent the corresponding pressure, by h. The equation to convert the input voltage to bar becomes (g – 0.6) * 35/(3.0 – 0.6).

As an exercise, the RAM transducers were set up on a test bench. The output of the transducers was measured against the corresponding distance, and the corresponding data was converted into equations using Excel. This was done to increase precision of the measurements. The 4 equations representing the transducers are shown in the formula box of the block diagram in Figure 2.15.

To allow for initial displacement offset when the transducers are position, an offset is allowed for. This is shown as 4 input into the 4 summing blocks. The data is then displayed on the charts "RAM 1", "RAM 2", "RAM 3" and "Hyd Pres". To record this data, the 4 channels are then built into an array using a "Build Array" block and passed into a case statement that is controlled by the "start/stop recording" button on the front panel. The case statement adds a header and timing information.

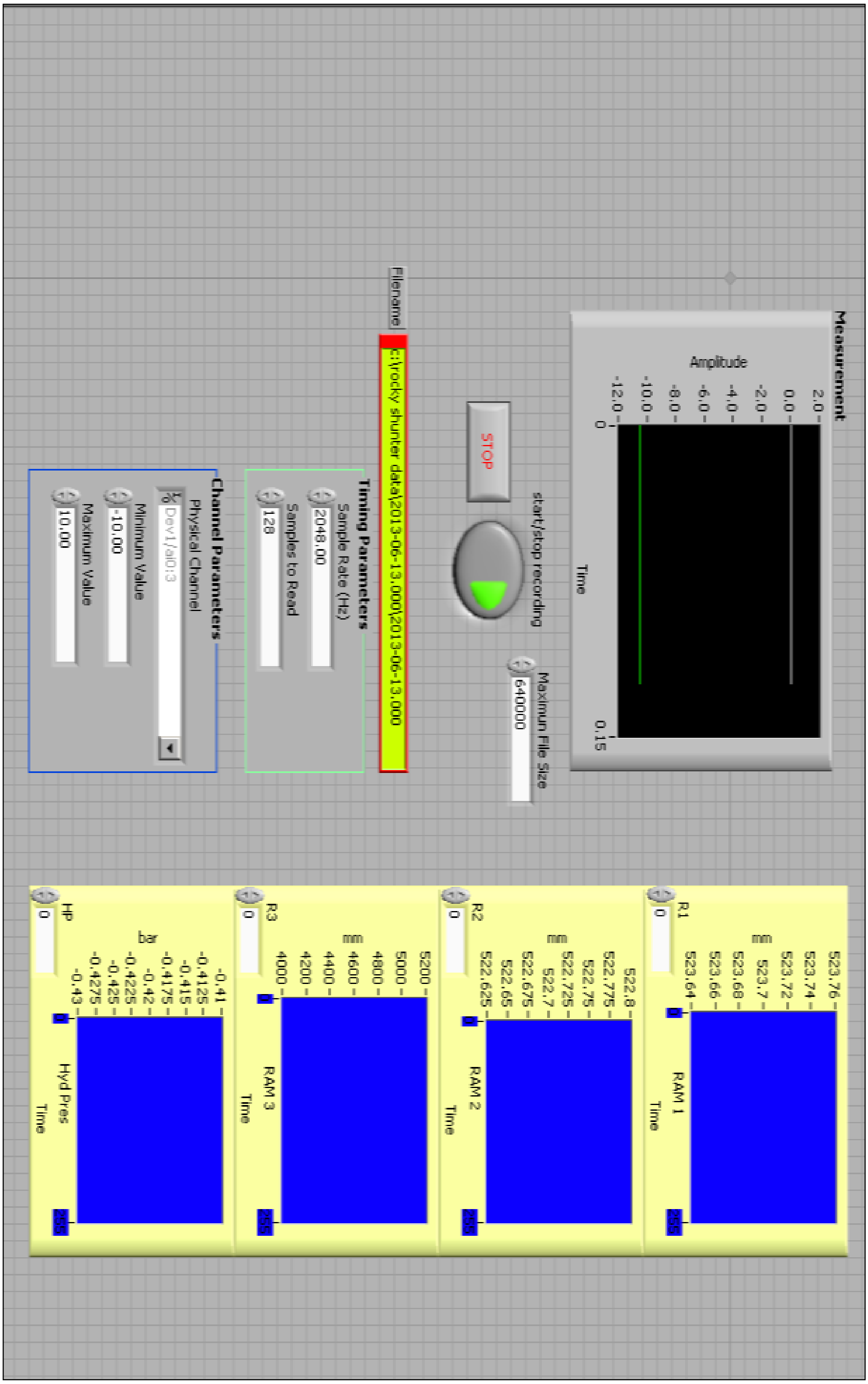


Figure 2-14: Screen output

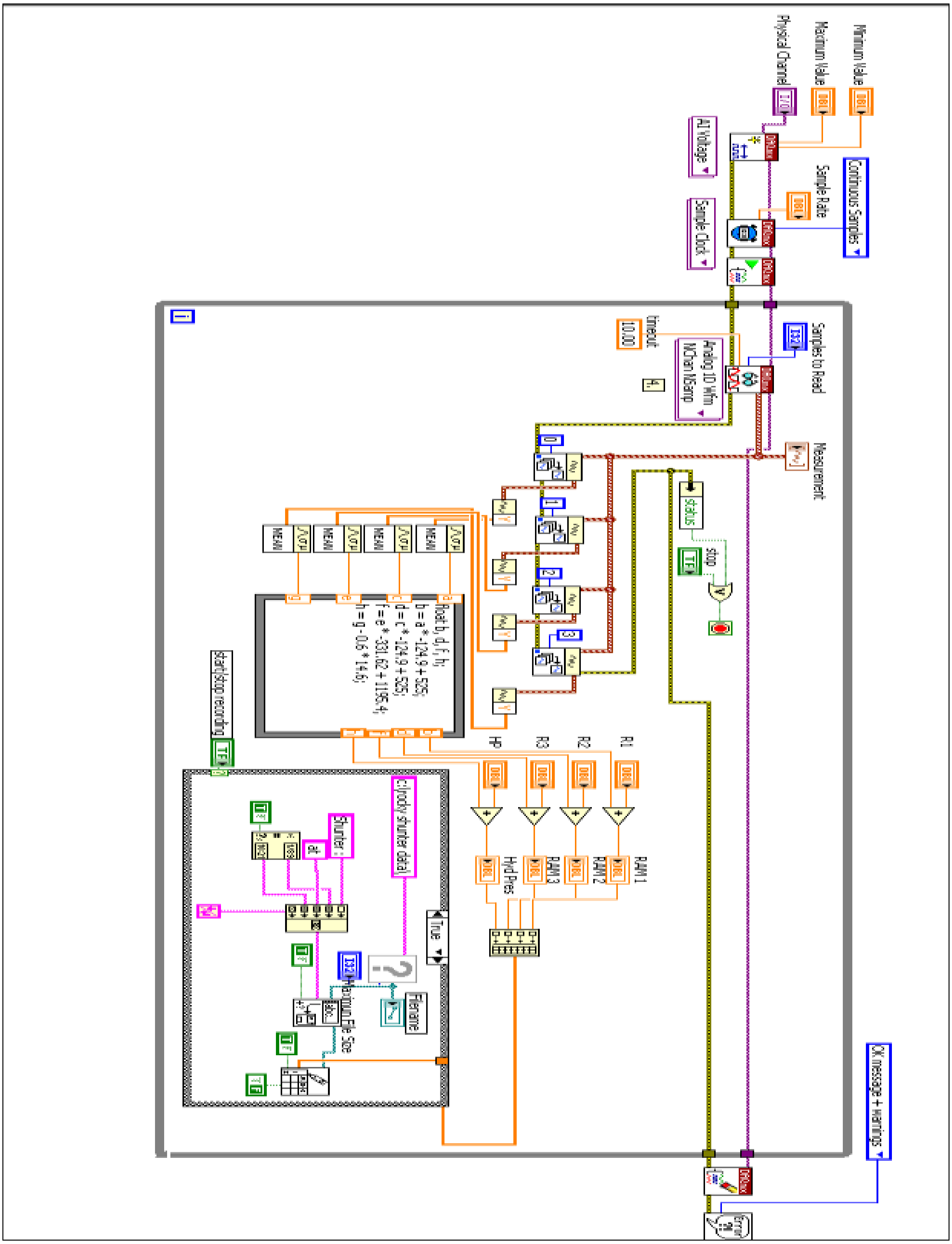


Figure 2-15: Block configuration

2.12 Financial Costs of Derailment

As result of a derailment and the subsequent investigations there is a significant disruption to workshop production due to the unavailability of the shunt tractor. The costs incurred are considerable. Following a derailment in August 2012 the shunt tractor was non-operational for a period of several weeks and the utilisation in the wagon shop dropped from 83 percent to 55 percent; 6200 man-hours were lost resulting in a loss of $979600 in chargeable earnings.

Chapter 3 - METHODOLOGY

From the research conducted into causes of derailments it appears flange climb is the most likely contributing factor to the derailments of the DN shunters. To try to validate if flange climb is the cause of derailments the lateral and vertical forces on the hi-rail wheels are to be quantified. There were various methods employed to try and achieve this goal. These methods were:

- fit monitoring equipment to the shunter,
- conduct a twist test on the shunter,
- regular checks of the hi-rail wheel profiles,
- weigh the shunter on the weighbridge, and
- calculate the lateral force based on the lateral movement between chassis and hi-rail wheels.

3.1 Fitment of Monitoring Equipment

Laser linear transducers were fitted to both hi-rail axle rams of the front axle of the DN 300; this is the axle that is prone to derailing. The transducers recorded the displacements in the rams during shunting operations and how quickly the rams reacted to any track deviation. A pressure transducer was installed in the hydraulic line that feeds the hi-rail system and recorded the pressures during operation. To record the lateral movement between chassis and the front hi-rail wheels a displacement sensor was mounted under the chassis level with the hi-rail wheels and focused on the rear of one of the hi-rail wheels.

The two linear transducers on the hi-rail wheels were designated Ram A and Ram B; Ram A was located on the passenger side and Ram B was on the driver's side. The transducer recording the lateral movement was designated Ram D.

Cameras were set up on each of the four hi-rail wheels to capture any wheel lift off during operation; the cameras only operated when motion was detected and all movement was recorded on a hard drive.

As the monitoring equipment was not going to be fitted long term, expected time frame two weeks, only temporary brackets were fixed to the shunter and the associated wiring only needed to be held up to ensure it does not get caught up or did not pose a potential hazard.

The power supply for the computer and the video hard drive was provided by a 12 volt DC to 240 volt AC pure sine wave inverter. A 24 – 12 converter provided the power for the inverter. A residual current device was placed on the outlet of the inverter to protect all personnel from risk of electric shock.

All signals from the transducers were feed into a National Instrument LAB VIEW device that in turn provided information to the VTC 6100 Industrial computer. The information from the four channel LAB VIEW device was stored in an excel spreadsheet on the computer hard drive. The times on the camera hard drive and the computer were synchronised to ensure all data would align.

As there was limited space in the drivers cab a screen was not connected to the VTC 6100 industrial computer. This meant there was no visual means of navigating around the computer to down load the data. This problem was overcome by installing a wireless router in the cabin of the DN 300 and using a laptop computer to remote into the on-board computer to retrieve the data.

3.2 Conduct static twist test

The static twist test on the DN 300 was conducted on a level section of track using the portable train weigher to measure the hi-rail wheel weights. The portable train weigher consists of two load cells mounted in a robust frame that fits between the rail lines. The weigher must be installed level to give an accurate reading of the wheel weights. To level the portable train weigher a 1200mm spirit level was used to check for level and then the appropriate shimming was placed under the frame. As the DN 300 is self-propelled, rather than jacking the machine to insert the jacking blocks under the desired wheel the machine was driven up onto the blocks, the park brake applied and the drive alighted from the cab. The engine was left running to ensure hydraulic pressure was maintained.

The blocks were placed on the rail in order of block height, that is, looking in the direction of travel the 10mm block was placed to be under the front rubber tyre, the 39mm block under the rear rubber tyre and the 41mm block was under the rear hi-rail wheel. The leading hi-rail wheel was placed directly on the track. Three separate readings were done with the vehicle travelling in a forward direction; the first run was done with the blocks on the left hand side rail, the second with the blocks on the right hand side and the third with the blocks again on the left hand side. Three more runs were done this time with the blocks in the reverse order; that is the 10mm block under the rear rubber tyre, the 39mm block under the front rubber tyre and the 41mm block under the front hi-rail wheel. The machine was driven off and on each time with the blocks being positioned under a different wheel. Once all readings had been recorded the results were entered into a purpose built spreadsheet. The wheel unloading must not exceed 60%.

3.3 Hi-rail wheel profiles

The hi-rail wheels have the same profile as locomotives and wagons, the LW-3 profile, but as the hi-rail wheels have a diameter of 220mm they are far smaller in diameter than the wagon or locomotive (minimum 660mm and 1040mm respectively) wheels so they do more revolutions per unit length and therefore wear more quickly. As flange angle can contribute to flange climb the hi-rail wheel profiles were checked using a purpose built recording device at regular intervals; usually fortnightly. The wheel profile recording device is shown in Figure 3.1. The device is basically a tracing apparatus that clamps to the wheel. The device consists of a clamp assembly, a sprung loaded moveable point, a stylus in the form of a ball point pen, a recording sheet and thread to move this assembly across the wheel profile. The stylus is attached to the sprung loaded moveable point and as the point is moved across the tread the profile is recorded on the recording sheet.

A new wheel profile was recorded for each hi-rail wheel following their refurbishment. These profiles were then used to compare with subsequent recordings. These can be seen in Section 4.3.

Figure 3-1: Profile recording device

3.3.1 Welding process

The hi-rail wheels had their profiles restored by firstly building up the tread by welding and then machining the correct profile. This process had not been undertaken before on site so was treated as Research and Development. The post weld finished profiled had to be reasonable wear resistant and yet softer than the rail so as to avoid wearing the rail.

The wheel material was believed to be 4140, a high strength metal.

The welding process was achieved in two stages, a buffer layer and a top layer. The weld material used in for the buffer layer was B2 (1.25Cr and 0.5Mo) and the electrode classification was E7015-B2L. Where 'E' designates electrode, 70 designates tensile strength, 15 designates position and current and the B2L designates the alloying composition.

To begin the process the wheel was heated to 125^{o}C and the welding process began at the outside of the wheel and worked in towards the flange. Starting at the flange would have seen too much heat input into this area of the wheel.

The top layer was a 35HRC metal to metal wear hard facing electrode. The classification for this electrode under AS/NZS 2576 is E1435-A4. Where 14 designates the process, 35 designates the hardness (Rockwell) and A4 designates the alloying composition.

3.4 Machine wheel weights

The Aurizon Rockhampton workshop is equipped with a weighbridge with capacity to weigh the largest locomotive in the fleet. The rails across the weighbridge are in multiple sections giving the weighbridge the capability of weighing individual wheels. The DN 300 was driven onto the weighbridge and positioned so that the wheels of each axle were positioned on a separate segment. This gave the wheel weights for both the hi-rail wheelsets and the rubber tyred wheels. The wheel weights of the hi-rail wheels were of interest as these determine the vertical force on rail as illustrated in Figure 2.9.

3.5 Calculate lateral forces

One component of the monitoring equipment on the DN 300 was a linear laser transducer set up to record the amount of lateral movement between the hi-rail wheels and the chassis, refer section 3.1. The data received from the displacement transducer was analysed to obtain the greatest amount of lateral movement during operation. This movement was simulated in a static test by applying a lateral force to the side of the hi-rail wheel. The process used to simulate the movement was the hi-rail wheels were lowered onto a greased steel plate laying on a smooth concrete floor. The grease was to provide a lower coefficient of friction between the plate and the hi-rail wheel flanges as the wheels were push across the plate. A portable hydraulic ram fitted with an inline pressure gauge was placed between a rigid shed column and the lowered hi-rail wheel and pressure was applied to the hydraulic ram via a hand operated pump. As the pressure was applied the hi-rail wheels were forced across the plate. In reaching the desired lateral movement the pressure on the gauge was recorded. Using the pressure recorded in the cylinder and the area of the piston, the force applied to the hi-rail wheel was determined by the equation, F = P x A.

The following equipment was used for the simulation:

- Enerpac portable hand operated hydraulic pump,
- Enerpac hydraulic ram model RC 102, capacity 10 ton,
- Pressure gauge, calibration due date 25/11/2013

3.6 Vehicle alignment

The DN 300 shunter has been in service for approximately 12 years and some years ago was involved in a major derailment that caused significant damage to the machine. It was believed the machine was repaired to its original condition but there was a possibility there was an alignment issue between the drive axles and the centre line of the machine. To try and rule out vehicle mis-alignment as possible derailment causation factors the alignment of the DN 300 was thoroughly checked. This involved checking the alignment of the drive wheels to the hi-rail wheels, the drive wheel axles relative to each other and the drive axles to the centre line of the machine. A deviation in axle alignment has potential to influence the hi-rail wheels angle of attack.

3.6.1 Steering

The centre pivot steering is controlled by a steering wheel operated power assisted orbital steering unit powering two opposing hydraulic steering rams. A lock valve is included in the hydraulic circuit to lock the steering in the straight ahead position for rail operation. Steering sensors automatically aligns the machine prior to the steering being locked. To ensure the steering is being locked in the straight ahead position the alignment was checked by simply measuring the distance between drive hubs on both sides of the vehicle after the alignment function was activated. The distance between hubs should be equal for an aligned machine.

3.6.2 Drive Axles

The front and rear drive axles are clamped in a relief pocket in the chassis side plates by a U-bolt arrangement. Inspection of this arrangement revealed there was no positive means of holding the axle from moving forward or backwards in the pocket and therefore could be angled in relation to the centreline of the vehicle. A skewed axle could influence the hi-rail wheels angle of attack.

3.6.3 Hi-rail axles

The hi-rail axles are attached to the vehicles at two locations, by the hydraulic rams and also by the rolled eye of the leaf springs that act as the pivot point for axle lift. A misaligned hi-rail axle could lead to an increased angle of attack for the hi-rail wheels. Dimensional checks were conducted to determine if the following alignments were correct:

- hi-rail axle perpendicular to centre line of machine,
- centre line of hi-rail axle to centre of machine.

Chapter 4 - RESULTS AND DISCUSSION

Investigations into the possible causes of the derailments of the shunt vehicles have been ongoing and the progress to date is discussed below. The primary focus of the investigation into the most probable cause of the derailments was focused on the DN 300 because a derailment involving this machine has the greatest impact on workshop production.

4.1 Risk assessment

A risk assessment was conducted in conjunction with all parties involved in the fitment of monitoring equipment to the shunt vehicles. The risk assessment document was requested from the Engineering Solutions document controller and a formal risk assessment was compiled. This risk assessment is required to be signed by all parties involved and then is submitted to the manager of Engineering Solutions for final signoff. Final sign is still pending but all parties were satisfied to work on the installation of the monitoring equipment prior to the risk assessment being signed off. A copy of the risk assessment is in Appendix G. As risk assessments are in place for the operation and maintenance of the shunt vehicles these risks were not included in the risk assessment for the fitment of monitoring equipment to the DN 300.

4.2 Vehicle alignment

4.2.1 DN 300 articulation alignment

The accuracy of the self-alignment function was checked on this machine driving along a straight section of track and activating the self-align function. The distance between the centre of the drive hubs on each side of the machine were measured and the length between centres on one side of the vehicle was longer than the other. This indicated the machine was not straight, that is, it was pivoted one way around the centre articulation pin. The misalignment could be easily seen by eye when looking along the side of the machine. When the machine was operated in this state a grinding sound could also be heard as the machine was driven along the rail; this was the flange binding on the rail head. The misalignment has the effect of increasing the hi-rail wheels angle of attack causing flange wear and increasing the chances of a flange climb derailment. Adjustment was made to the alignment sensor by Aurizon maintenance staff and the machine alignment was again true but after operating for a short time the machine was again pivoted slightly around the centre pin.

To try and establish the cause of the creep in the vehicle alignment the hydraulic steering rams were removed and dismantled. Inspection of the ram components found that the seals in one hydraulic ram were not full size. Either undersize seals had been fitted to the piston or the seals were worn and hydraulic fluid was passing the piston allowing articulation of the machine. Figure 4.1 below shows the worn seal on the left. As the steering rams operate together it is unlikely that only one ram should be affected with wear therefore it is probable the incorrect seals were initially installed on the piston. The seals were replaced in both steering rams and repeatability of the alignment was obtained. However during recent operations there is once again a drift in the alignment. The operators report that after repeatedly negotiating several curves during shunting and then when on a straight track again when the alignment function is activated there is noticeable movement in the machine as it aligns. This has not as yet been investigated but it appears the constant negotiation of curves in one direction maybe placing additional pressure on the steering rams causing hydraulic fluid to bypass the seals.

Figure 4-1: Steering ram seals

4.2.2 Axle alignment

Following a derailment on a near straight section of track (a slight curve to the left in the direction of travel) the DN 300 was taken into the workshop to have the axle alignment checked. The machine was placed on stands and the rubber tyres were removed. The alignment of the drive axles was checked by running a straight edge across the front of the hubs and measuring the distance to the chassis at a point equidistant from the front and rear of the hub. It was found the front axle was slightly skewed, approximately one degree, in the same direction as the misalignment around the centre pivot. Although only a small angle of misalignment it would have contributed to the overall vehicle alignment on track, influencing the hi-rail wheels angle of attack. The alignment was corrected.

4.3 Wheel profile

Due to the misalignment in the machine the hi-rail wheels had suffered considerable flange wear. Supply of a new set of hi-rail wheels had a considerable lead time so it was decided to remove the wheels and build up the flange and tread by welding – refer Section 3.3.1. After re-fitment of the hi-rail wheels to the DN 300 the wheel profiles were taken so as to establish a base line with which to gauge future wheel wear. As mentioned in Section 2.6 flange angle is an important factor in preventing flange climb. To ensure flange angle were satisfactory for service the hi-rail wheel profiles were taken at regular intervals and were compared with the new profile of 20th February 2013; post build up. The two profiles were overlayed and any deviation from the new profile was easily seen. The new wheel profile was inserted as a dashed line on all subsequent profiles. This illustrated the level of wear experienced on the particular wheel. The wheel profile for the front right hi-rail wheel is shown in Figure 4.2 below and the profiles for the remaining three hi-rail wheels are shown in Appendix E.

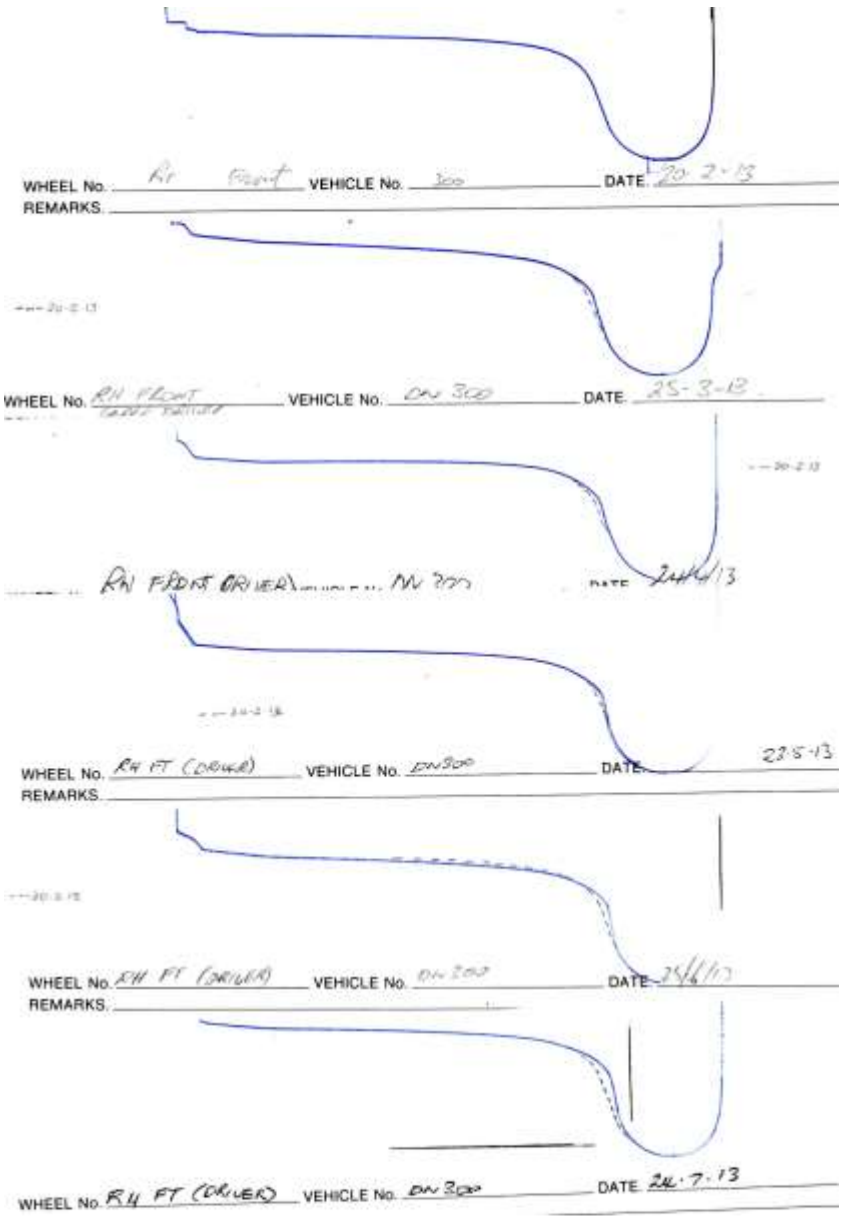


Figure 4-2: Front right hi-rail wheel profile

Wear on the wheels was visible after approximately one month's service. Inspection of the four wheel profiles taken on the 24.07.2013 shows all wheels have worn but the wear patterns are not all the same. The front right and the left rear wheels have similar wear patterns, so too does the front left and the right rear. This indicates the diagonal wheels have the same wear patterns. The reason for these particular wear patterns could be attributed to the creep in the alignment system. Even though the machine operators are vigilant and regularly re-align the machine there are times when the machine is operating slightly misaligned.

4.4 Concrete cutting

In Section 2.9 NARCOA reported that grade crossings and turnouts present hazards to hi-rail vehicles due to the highway tyres riding up on the pavement, Figure 4.3, causing the lift off of the hi-rail wheels.

Figure 4-3: Tyre supported by roadway

A section of curved track within the workshops yard runs through a concreted roadway where the top of the rail is level with the top of the concrete. There have been numerous derailments along this section of track, the cause of which is likely to be hi-rail wheel lift off or reduced vertical force due to the highway tyres riding high. To try and counter this issue the concrete has been relieved each side of the rail so that no part of the rubber wheels touched the concrete, refer Figures 4.4 & 4.5. Since the concrete has been removed from each side of the rail there have been no further derailments in this section.

Figure 4-4: Pre- concrete cutting

Figure 4-5: Post concrete cutting

4.5 Twist test

A twist test was completed for the DN 300 as per Section 2.8. The percentage of wheel unloading was 3.3% for the Leading end and 13.2% for the Trailing end; these percentages are well within the allowable 60%. Based on these figures wheel unloading due to vehicle or track twist is not a contributing factor to the derailments.

4.6 Vehicle weighing

The primary objective of weighing the DN 300 was to obtain the wheel weights of the hi-rail wheels on the rail. To facilitate the connection of the lift rams to the hi-rail axle there are short levers welded to the axle. These levers have two holes where connection can be made, refer Figure 4.6. Machine weights were taken for both pin positions; the weights are displayed in Table 4.1 below.

Figure 4-6: Hi-rail lift ram attachment points

The as measured total mass figures in Table 4.1 differ from the DN 300 specification axle masses shown in Table 2.1. The specifications stated the front and rear axles had a mass of 7500 kilograms whereas the masses obtained on the weighbridge are 6130 kilograms and 6340 kilograms for the front and rear axles respectively.

Table 4-1: DN 300 wheel loadings

	DN 300 wheel weights - comparing different hi-rail ram set up			
	Clevis pins in rear holes		Clevis pins in front holes	
	LHS (t)	RHS (t)	LHS (t)	RHS (t)
Hi-rail wheels - rear	1.09	1.03	1.21	1.24
Rubber tyres	2.21	2.01	1.98	1.87
Rubber tyres	2.27	2.19	2.22	2.16
Hi-rail wheels - front	0.85	0.82	0.87	0.92
Side total mass	6.42	6.05	6.29	6.19
Total vehicle mass	12.47		12.48	

As can be seen from Table 4.1 after changing the pin positions there is minimal effect on the left hand side front high rail wheel, difference of 20 kilograms, whereas the right hand side there is a difference of 100 kilograms. The rear hi-rail wheels are significantly more affected with the left hand side changing by 120 kilograms and the right hand side by 210 kilograms. The normal operating position of the pins is in the rear hole. The force on the rail due to the hi-rail wheel mass is of interest as it is the vertical force (V) in the L/V ratio that is a critical factor in determining if a flange will climb the rail head.

Whilst authority to operate the weighbridge was current it was decided to check the wheel loadings on the DN 100 shunter for future reference; these are listed in

Table 4.2. Unlike the DN 300 the hi-rail wheel loadings on the DN 100 vary by only 15 percent from the lightest to the heaviest wheel. There is only one connection point on the arms off the hi-rail axles on this machine.

Table 4-2: DN 100 wheel loadings

	Axle Position (Wheel loadings in tonnes)			
	Rear hi-rail	Rear rubber	Front rubber	Front hi-rail
Left side	0.55	0.99	0.86	0.51
Right side	0.6	1.14	0.87	0.57
Axle load – on road	3.28		2.81	

4.7 Data analysis

Data was collect during the operation of the DN 300 for ten consecutive working days. Data was only collected while the machine was operating; when the machine was idle for an extended period the operator's isolated power to the monitoring equipment. When power was again restored the monitoring equipment powered up and commenced recording. Each data file had the capacity for approximately ten minutes data and then a new file was created. Depending on the days shunting activities the number of data files for the day could be as many as thirty; giving five hours of data to be analysed.

The data files were in xls. format and an extract from a typically file is shown in Table 4.3. Columns 1 to 7 are the raw data; columns 1 to 3 give the time of sampling and columns 4 to 6 are the distances between the laser sensors and the reflecting surface. Column 7 is the hydraulic pressure. Columns 8 to 11 are columns 4 to 7 that have had the data modified by subtracting the initial values in the columns to create a zero point for easier data analysis.

Table 4-3: Typical data file

1	2	3	4	5	6	7	8	9	10	11
Hrs	mins	sec	Ram 1	Ram 2	Ram 3	HP	Ram 1	Ram 2	Ram 3	HP
2	24	3	260.627	245.108	493.106	33.558	0	0	0	0
2	24	3	260.623	245.108	493.131	33.407	-0.004	0	0.025	-0.151
2	24	3	260.638	245.111	493.116	33.516	0.011	0.003	0.01	-0.042
2	24	3	260.64	245.125	493.134	33.372	0.013	0.017	0.028	-0.186
2	24	3	260.631	245.12	493.135	33.549	0.004	0.012	0.029	-0.009
2	24	3	260.641	245.13	493.147	33.514	0.014	0.022	0.041	-0.044
2	24	3	260.63	245.114	493.099	33.328	0.003	0.006	-0.007	-0.23
2	24	3	260.629	245.114	493.052	33.521	0.002	0.006	-0.054	-0.037

Initially all files were graphed to obtain a quick visual of what happened during that period. As the graphed contained ten minutes of data that was recording at sixteen hertz meant the graph was very tight and deviations in the lines was difficult to see but gave a general overview of the situation. A typical graph is shown in Figure 4.7 below. The lines for the two hi-rail and the lateral displacements are steady and as one would expect. However the line for the hydraulic pressure shows four significant deviations; this is not typical of a constant pressure system. To gain a fuller understanding of the movements of each line on the graph the lines were analysed individually by plotting the section of the line of interest for a shorter period. The detailed analysis for Rams 1 to 3 and the hydraulic pressure are discussed in Sections 4.7.1 to 4.7.3.

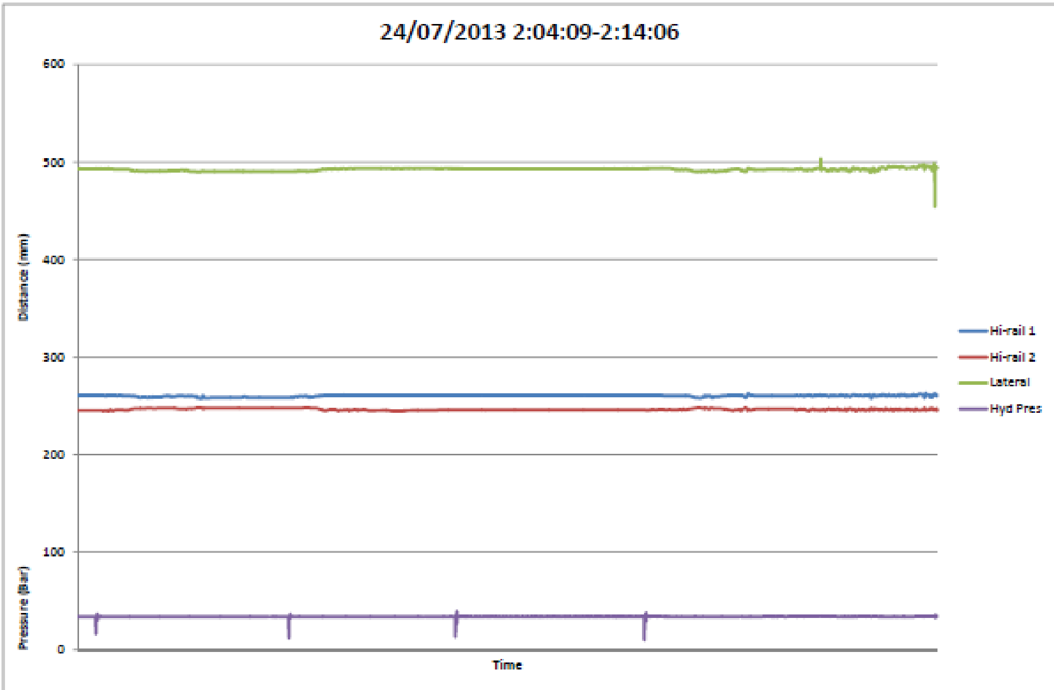


Figure 4-7: Typical graph of machine operation

4.7.1 Lateral movement

The lateral movement displacement transducer recorded the movement between the chassis and the hi-rail wheels and is shown as Ram 3 in Figure 4.7. This shows there is little movement between the chassis and the hi-rail wheels as would be expected based on the axle securing arrangement. To show the extent of the lateral movement in the machine during operation, the data for a twelve second period was plotted and can be seen in Figure 4.8. This particular period has less than 1mm of lateral movement. Analysing lateral movement data for the recording period showed the greatest lateral movement was just on 10mm. Issues were encountered with unrealistic readings with some lateral movement recordings; these were either very short distances or long distances in the range of 100 plus millimetres. Movements of these distances would require very large forces and would have resulted in damage to the machine. Investigation revealed the very short distances were a result of long grass between the two tracks; the laser was reflected of the grass giving a short reading. The longer readings were believed to be caused by the reflective tape that was applied to the back face of the hi-rail wheel that the laser sensor was focused on. The reflective tape was removed and the back face of the wheel was painted white; there were no further issues with long distances.

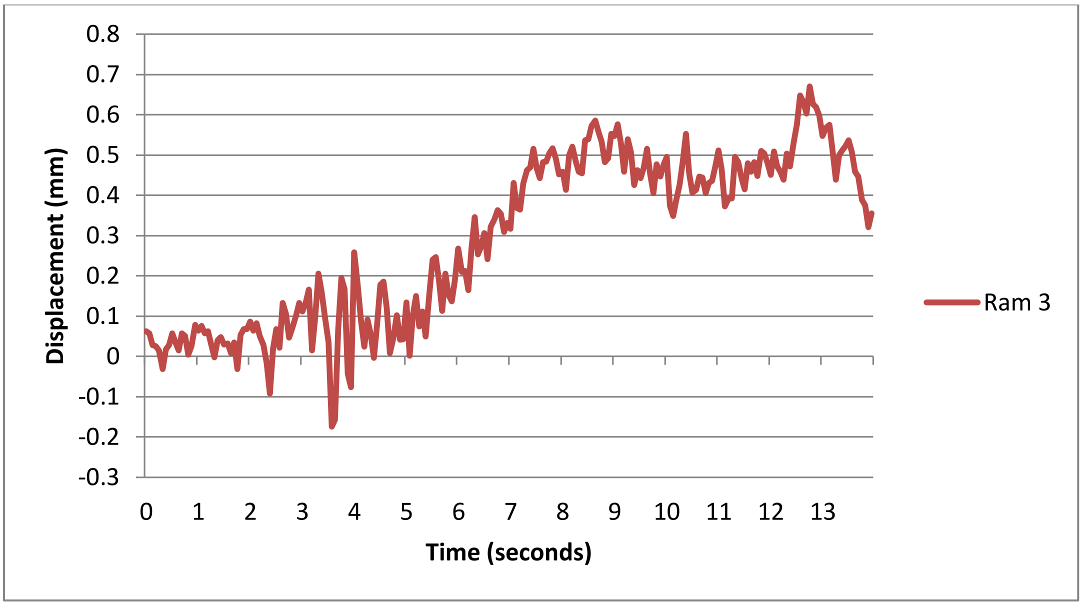


Figure 4-8: Lateral displacement

4.7.2 Lateral forces

Lateral forces on the hi-rail wheels were determined as outlined in Section 3.5. The results indicated a linear relationship between the force applied and the distance moved. The force required to move the hi-rail wheels 10mm in a lateral direction was 4988N.

4.7.3 Linear displacement

The rail lines the DN 300 operates on have slight dips and undulations due to movement in the ground supporting the sleepers. These deviations in the track can be seen in the Figure 4.9 as the hi-rail rams extend and retract as the wheels follow the rail profile. As can be seen from the figure the extent of the extension/ retraction is minimal. Analysis of the complete set of recorded data shows the greatest displacement is 5.5mm and 5.3mm for rams 1 and 2 respectively.

Referring to Figure 4.9 it can be seen that the movements of the two hi-rail rams are mostly 180 degrees out of phase. The reason for this occurring is due to a load control valve in the hydraulic line feeding the hi-rail lift rams. The load control valve will hold the pressure in the hydraulic line provided the directional control valve is closed. In effect the hydraulic fluid is captive within the hydraulic system downstream from the valve and the only flow of hydraulic fluid is between the two hydraulic rams. Therefore if one ram extends to follow a dip in the track the fluid required for this to occur is provided by the other ram retracting. The hydraulic circuit for the DN 300 is contained in Appendix D.

As the axle displacements are small and mostly even there is no indication that there is an issue that could be contributing to derailment.

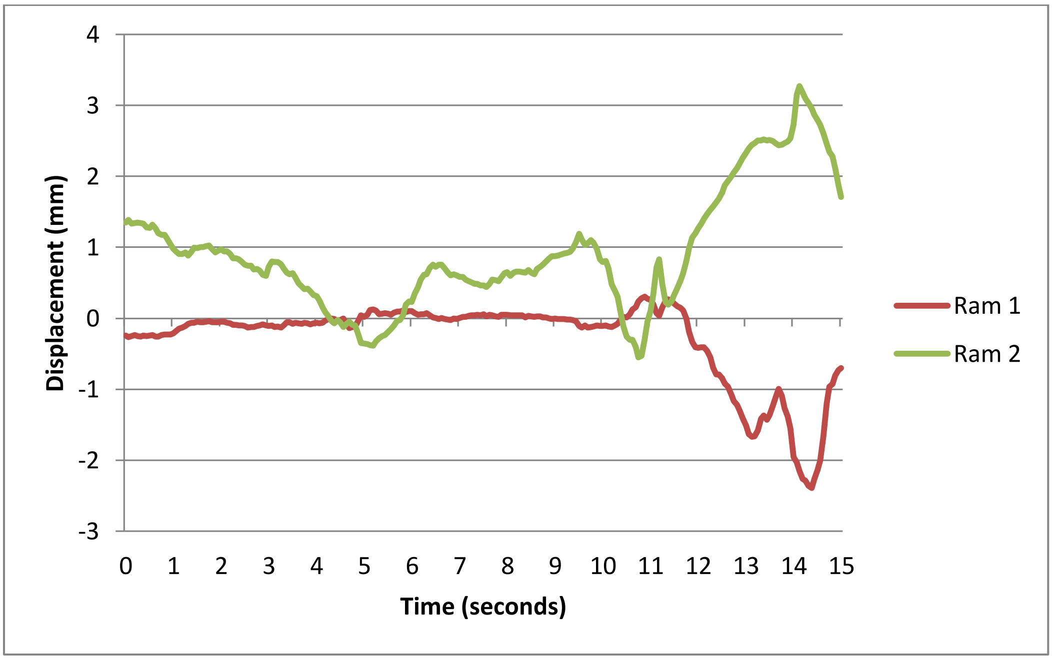


Figure 4-9: Hi-rail wheel displacements

4.7.4 Hydraulic pressure

The hydraulic pressure on the hi-rail system in the DN 300 is controlled by a pressure reducing valve set to 400 psi, approximately 27.57 bar. Rohner 1995, states 'the main function of a pressure reducing valve is to limit and maintain a constant downstream pressure (sub circuit pressure), regardless of fluctuations in the main circuit upstream.

Examination of Figure 4.7 shows there are four drops in the hydraulic pressure in a ten minute period; clearly the system is not maintaining a constant downstream pressure. The extent of one of these pressure drops is shown in Figure 4.10. Analysis of the complete set of data for the recording period revealed that the drops in the hydraulic pressure are intermittent. Some days saw the system run without pressure loss for an hour whilst on other days there were pressure losses in the majority of the data sets for the day.

Pressure losses in the hydraulic system saw pressures as low as 7.7 bar. These pressure drops were of only short durations, typically one to three cycles. Either side of the lowest pressures there was a drop off in pressure leading to the lowest pressure and then an increase from lowest to around half the system pressure. Following the pressure drop the system pressure fluctuated above and below the normal operating pressure. During these fluctuations the diesel engine driving the hydraulic pump appeared to run smoothly; there was no monitoring to confirm this but the operators did not report any rough engine nor did they observe any issue in the hydraulics.

The hydraulic pump is a direct drive axial piston pump so it is unlikely that the pressure reductions could be a result of the hydraulic pump.

The loss of pressure in the hi-rail system is most likely due to a faulty pressure reducing valve. The maintenance fitters on site that service the DN 300 advise this particular valve was replaced many years ago; the reason for replacement is unclear but based in this information it appears there may be a valve reliability issue. The present pressure reducing valve in the hydraulic system is an adjustable type with a pressure range of 14-85 bar. As the required system pressure is 33-34 bar the present valve is operating in the bottom half of the range. Parker Hydraulics valve catalogue states 'You want to choose the setting that best meets the operating range'. A pressure reducing valve with an operating range of 7-40 bar, such as the EATON PRV1-10-S-0-12/4.5 would be closer to the operating range.

To ensure the pressure loss was not caused by dirty or substandard hydraulic fluid a sample of the fluid was sent to a condition monitoring laboratory for analysis. The laboratory confirmed the hydraulic fluid was satisfactory thereby ruling out inferior hydraulic fluid being the cause of pressure loss. The laboratory report is contained in Appendix F.

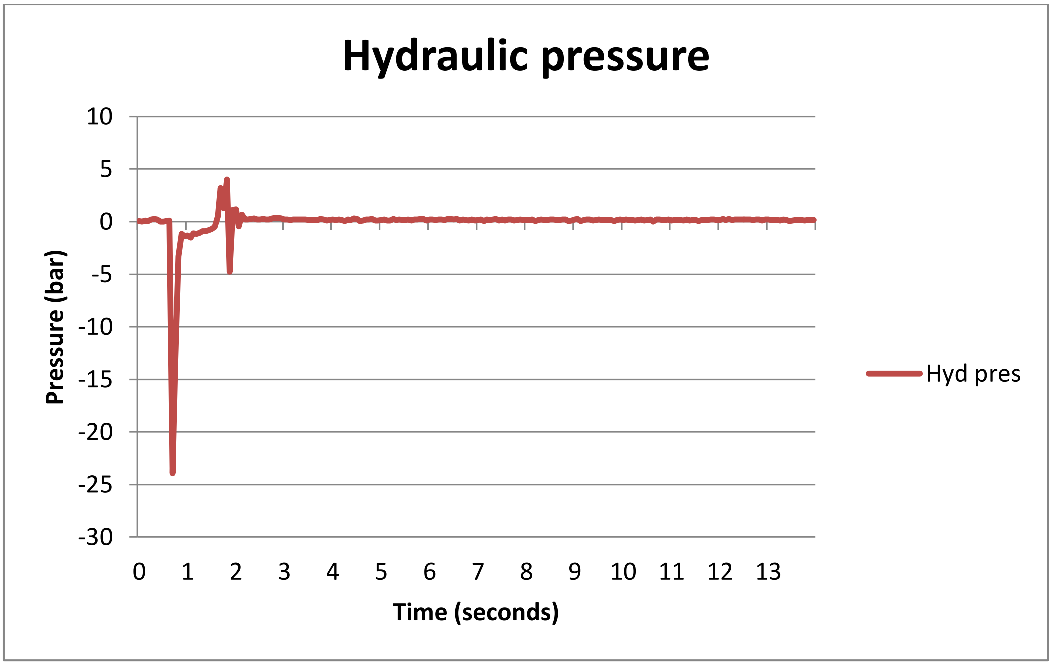


Figure 4-10: Hydraulic pressure fluctuations

4.8 Effects of hydraulic pressure loss

A loss of hydraulic pressure in the hi-rail wheel system has the effect of reducing the downward force on the rail. To determine the net wheel load on the rail during a period of reduced hydraulic pressure the percentage hydraulic pressure loss was applied to the known wheel load on rail, Table 4.1. The average hydraulic pressure during normal operation is 33.5 bar and the minimum observed pressure was 7.7 bar. This equates to a 77 percent reduction in pressure. In all recent derailments it was the front wheels of the DN 300 that derailed first; on the driver's side. Taking the driver's side wheel load and applying a 77% reduction the wheel load becomes 0.188t. The vertical force is now only 1850N.

The duration of the pressure loss observed from the data collected to date is in the order of 187 milliseconds. This period of time may be long enough if the vehicle is travelling to have the flange climb the rail.

The hi-rail wheels are approximately 220mm in diameter when full size, giving a circumference of 691mm. The maximum allowable shunt speed on site is 5 km/h (1.388m/s). At this speed the time taken for one complete wheel revolution is approximately 500 milliseconds. Based on the durations for the pressure loss a wheel would turn approximately just over a third of one revolution. This is approximately 258mm in distance along the track and most probably sufficient distance for the flange to have climbed the rail. Once the flange is on top of the rail head all control over the guidance on rail is lost and the flange will continue to run along the rail head until either falling down on the inside of the rail, the normal location or going off on the outside edge of the rail.

4.9 LV Ratio

As previously mentioned in section 2.5 the ratio between the lateral and vertical forces is a determining factor in flange climb. To investigate if flange climb could be a contributing factor to derailment the wheel flange angle at the plane of contact was established using a plaster cast was taken of a section of rail head at a known derailment location. This profile was used in conjunction with the hi-rail wheel profile and the wheel flange angle at the plane of contact (β) was determined to be 77 degrees, refer figure 4.11. The critical L/V ratio was calculated using the equation below with β = 77 and μ = 0.4 (the mid range of the RISSB mentioned in section 2.5). The L/V ratio was determined to be 1.316.

$$\frac{L}{V} = \frac{\tan\beta - \mu}{1 + \mu\tan\beta}$$

Where L = Lateral force at the wheel flange

V= vertical force on the wheel

β =Wheel flange angle at the

plane of contact

μ = Coefficient of friction at flange/

rail contact point

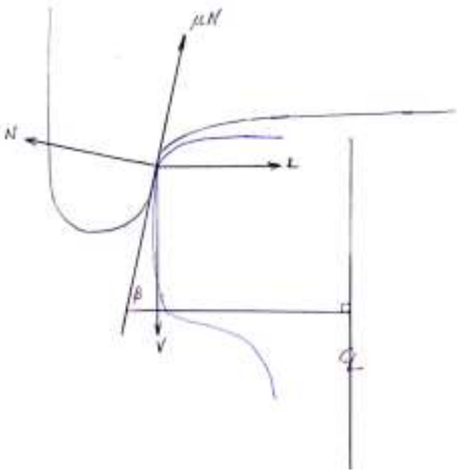


Figure 4-11: Flange angle-using plaster cast and wheel profile

The AAR Wheel Climb Duration Limit states ‘the individual wheel L/V should not exceed 1.0 on any wheels measured and the values are not to exceed indicated value for a period greater than 50 milliseconds per exceedence. This aligns with Aurizon’s standards. As the duration of the hydraulic pressure loss is up to 187 milliseconds it is feasible that flange climb could occur as the L/V ratio is exceed for a period 3.7 times longer than the recommended.

The L/V ratio was also calculated using the forces recorded for the lateral movement (Section 4.7.2) and the reduced wheel loading (Section 4.8). This calculation returned an L/V ratio of 2.69. This is greater than the critical L/V calculated and confirms flange climb could occur during periods of reduced hydraulic pressure.

4.10 Rubber tyres

Following the March 2013 derailment of the DN 300 all rubber tyres were changed due to the tread surfaces being deeply grooved. The rubber tyres are required for vehicle traction and braking. As there is only a narrow contact section between the tyre and the rail head the tractive/ braking forces are applied through this narrow section of the tread and as a result of this force concentration grooves wear in the tread. The hi-rail wheels provide the guidance on rail and in cornering the rubber tyres slide across the rail as they follow the curve. If the grooves in the rubber tyres become sufficiently deep the sliding across the rail becomes more difficult if at all possible. If the tyre does not slide across the rail but remains running in the groove there is an increased lateral force applied to the hi-rail wheels as the rubber tyres tend to follow the rail. This increased lateral force will be in addition to any existing lateral force and could result in the total lateral force being greater than the vertical force on the wheel.

Figure 4-12: DN 300 tyre wear

Varley, the company who bought out the original manufacturers of the DN shunters was contacted in relation to the tyre issues and their response was to reduce the inflation pressure. The tyre pressures were reduced and the machine was trialled. The reduced tyre pressures were not successful as the tyres deform and slide off the rail head when cornering. Freighquip advised they had similar experiences with lower tyre pressures and tight radius corners. At the reduced pressures there was evidence of interference between the vehicle chassis and the side wall of the tyres. The tyre pressures were returned to maximum shop air pressure of 105 PSI; less than the maximum allowable tyre pressure but found to be a satisfactory operation pressure.

To try and prolong tyre life thought has been given to changing the tyre orientation on the rim by removing the tyre and installing it in the reverse direction. This would have to be done before the groove in the tyre became too significant. It would not work if the tyre was of the uni-directional type. To date the changing of the tyre orientation has not been done as the grooves have become too deep.

It is difficult to quantify how much extra lateral load is placed on the hi-rail wheel in cornering as a result of operating with grooved tyres but the derailment issues with the DN 100 were eliminated by replacing all rubber tyres on the machine. Although DN 100 is a lighter machine and the wear on the tyres was more a raised line in the tread it highlights the fact that tread profile can be affect the lateral force on the hi-rail wheels. The DN 100 tyre wear is shown in Figure 4.13.

Figure 4-13: DN 100 tyre wear

4.11 Track Conditions

Curves in the track where derailments had occurred were measured to determine the radius to ensure they were compliant with the network track specifications. The radii of the curves were calculated using the equation below, Machinery's Handbook 26th Edition:

$$r = c^2 + 4h^2/8h$$

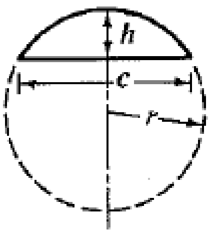


Figure 4-14: Curve radius calculation

Where

Table 4-4: Track curve radii

c (m)	h (m)	r (m)
21	0.55	100.5
17	0.38	95.25

Both radii of the curves were greater than the minimum 60m radius the DN 300 is capable of negotiating so therefore the curvature of the bend was determined not to be a contributing factor to the derailments.

The track elevations at known derailment locations were checked to determine if track twist was a contributing factor. Measurements were taken at 500mm intervals for 20m each side of the derailment location on both rails. The result showed there was only a maximum of 10mm height difference between the rails at any point. The deviation in rail head heights is not considered large enough to contribute to a derailment.

4.12 Connection to Rollingstock

It is usual workshop's shunting practice to have a shunt runner connected between the shunt tractor and the rollingstock that is being shunted. The shunt runner is a purpose built ballasted wagon that provides additional braking capacity to the shunter. The shunt runner was for a time out of service for overhaul and it was during this period that the shunt tractor was directly coupled to the rollingstock. Issues were observed with some of the couplers on wagons were stiff; they were not easily slid across the supporting plate. This was witnessed mainly on the wagons that are used to carry coal wagon bodies to the grit shop for abrasive blasting. These couplers are prone to becoming contaminated with grit from the abrasive blasting process. Couplers are designed to have 15 degrees of movement from the centreline of the wagon. The lack of movement in some couplers acts like a rigid link between the wagon and the shunt tractor and had the effect of trying to hold the tractor in line with the wagon. This meant that in cornering the wagon was trying to hold the tractor in a straight line thereby causing additional lateral forces on the hi-rail wheels.

Chapter 5 – CONCLUSIONS

5.1 Project outcomes

Research into derailments highlighted there are six major causes of derailments as discussed in section 2.3. Investigation of the DN 300 derailments soon discounted the derailments being caused by, wheel lift off, rail gauge widening, wheel obstruction and wheels rotating over the rail as there was no evidence to support these mechanisms. This left one possible derailment cause, flange climb. The factors contributing to flange climb were further investigated to determine if in fact flange climb was a contributing factor to the derailments of the DN 300.

Flange climb is dependent on several factors, namely, the L/V ratio, the coefficient of friction and the angle of attack of the hi-rail wheels. The angle of attack of the hi-rail wheels is dependent on the axle alignment to the centre line of the rail. Accelerate wear of the hi-rail wheels indicated there may have been an alignment issue with the hi-rail wheels and investigation found there was indeed a vehicle alignment issue. The alignment was subsequently rectified. To determine the L/V ratio the DN 300 was fitted with monitoring equipment to log the in-service parameters of the machine. Data logging was conducted over a ten day period.

Analysis of the data collected revealed there was an intermittent drop in the hydraulic pressure in the line to the hi-rail wheels. The pressure drop was significant as the pressure dropped to 7.7% of system pressure. This percentage drop when applied to the vertical force produced by the hi-rail wheels resulted in an L/V ratio of 1.3 for around 187 milliseconds, far exceeding the AAR specification.

The groves worn into the tread of the rubber tyres due to the constant running along the track have the effect of increasing the lateral force on the hi-rail wheels and therefore contribute to a larger L/V ratio. Although this has not been quantified the DN 100 that was frequently derailing has not derailed since having the grooved tyres replaced.

Based on the fact there is a significant loss of hydraulic pressure in the hi-rail wheel system coupled with the misalignment issue it is believed the derailments of the DN 300 were due to flange climb. The misalignment produced an unfavourable angle of attack in the hi-rail wheels and the reduced hydraulic pressure lead to a loss of the vertical force on the rail thereby allowing the flange to climb. Once on the rail head the hi-rail wheel provided no directional control and in most cases would lead to derailment.

There has not been a derailment of the DN 300 since May 2013; prior to this there were six derailments since August 2012. The repairs and modifications to the DN 300 as a result of the derailment investigations have resulted in significant cost benefits to the company.

5.2 Further work to be done

Technical issues associated with the monitoring equipment on the DN 300 delayed data collection that resulted in the equipment not able to be fitted to the DN 100 in time to collect data for this report. The monitoring equipment is to be removed from the DN 300 and fitted to the DN 100 to observe the operating parameters.

5.3 Recommendations

The following recommendations are made in an effort to reduce the risk of flange climb leading to derailment to as low as reasonable achievable.

- Replace the pressure reducing valve to try and eliminate the intermittent loss in hydraulic pressure,
- Install a pressure transducer in the hydraulic line above the pressure reducing valve to monitor hydraulic pump pressure before removing the equipment,
- Trial changing the position of the attachment of the front hi-rail rams to increase the load on the wheels on the rail – this could affect braking and traction and would have to be monitored closely to ensure there were no safety issues,
- Change out the rubber tyres when the grooves in the tread reach a predetermined limit,

- Update the work instruction on the operation of the DN 300 and DN 100 to have the operators regularly perform the alignment function.

References

Jean-Bernard Ayasse and Hugues Chollet 2006, 'Wheel – Rail Contact', in Simon Inwnicki (ed), *Handbook of Railway Vehicle Dynamics*, Taylor and Francis Group London.

Huimin Wu and Nicholas Wilson 2006, 'Railway vehicle Derailment and Prevention', in Simon Inwnicki (ed), *Handbook of Railway Vehicle Dynamics*, Taylor and Francis Group London.

Ulf Olofsson and Roger Lewis 2006, 'Tribology of the Wheel – Rail Contact', in Simon Inwnicki (ed), *Handbook of Railway Vehicle Dynamics*, Taylor and Francis Group London.

Roger Lewsi and Rob Dwyer-Joyce 2006, 'Industrial Lubrication Practice – Wheel/Rail Tribology', in Simon Inwnicki (ed), *Handbook of Railway Vehicle Dynamics*, Taylor and Francis Group London.

Williams, Warren 2012, 'Derailment Quotient Sensitivity to Angle of Attack Applying The Method of Yokose', Conference on Railway Engineering 2012 pp501-510.

Jackson, RD Jr 2001, *Hi-Rail Wheel Assembly for Improved Traction,* US Patent 6298792 B1

Yard, WJ 1972, *Convertible Rail-Highway Shunting Locomotive*, US Patent 3638579

Tyrell, D, Weinstock, H, Greif, R 1986, Wheel Unloading of Rail Vehicles Due to Track Twist, pp1-58, Engineering Village.

NARCOA 2011, HI-Rail Vehicle Purchasing and Operating Guidelines, viewed 8thApril 2013www.narcoa.org/docs/hyrailguide.pdf

RISSB (Rail Industry Safety and Standards Board) 2013, *Derailment Investigation and Analysis Guideline.*

Perkins, OS 1962, *Road Rail Vehicle,* US patent 3020858

Yard, WJ 1969, *Convertible Rail-Highway Shunting Vehicle*, US patent 3638579

McCauley, C, *Machinery's Handbook 26th Edition*, *Industrial Press Inc.* New York

Appendix A – Project Specification

University of Southern Queensland

FACULTY OF ENGINEERNG AND SURVEYING

ENG4111/4112 Research Project

PROJECT SPECIFICATION

FOR:	Chris Langes
TOPIC:	Investigation of shunt vehicle derailment
SUPERVISOR:	Dr Jayantha Epaarchchi
	Darren Brehmer, Aurizon
SPONSERSHIP:	Aurizon
PROJECT AIM:	To find the root cause of the shunt vehicle derailments
CONFIDENTIALITY:	This project is to be treated as confidential and not for public display (24th October 2013 – not required)

PROGRAMME: (Issue B, 5th April 2013)

1. Research operational issues with other Hi-rail wheel vehicle operations,
2. Design a vehicle monitoring system to analyse vehicle movement during shunting operations,
3. Analyse operational data,
4. Conduct twist test on vehicle to determine if wheel forces on track are sufficient,
5. Pneumatic tyre/rail compatibility,
6. Investigate any track issues that could be contributing factors to the derailments,
7. Investigate if environmental influences could be contributing factors to the derailments,
8. Recommendations Based on Findings
9. Submit academic dissertation on the research.

AGREED ………………………….(Chris Langes) ………………………………..(Supervisor)

Date 13/03/2013 Date / /2013

Examiner/Co-examiner………………………………….

Appendix B – Transducers

Hydraulic

Model 326F

Low-cost Pressure Transducers

SENSOR

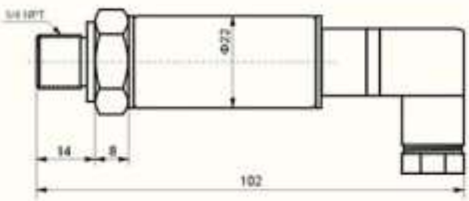
Based on BCM strain gauge technology, BCM model 326F transducers are designed for pressure measuring in low-cost applications, the transducers are made 100% from stainless steel in mass production. With a small dimensions, It can use at many kinds mechanical equipments, widely used in industries of oil, chemical, water projects, electric power, refrigeration equipments and air compression etc.

The transducers are compensated in a wide temperature ranges and have a nice long term stability, the output of pressure transducers is mili-volts or amplified signals, such as 0~10 Vdc or 4~20 mA.

Features:

- wide measuring ranges from 0/10 bar to 0/700 bar
- measuring accuracy of 0.5, 1 %FS optional
- 100% made from stainless steel
- rigid and compact construction
- small dimensions, cost effective
- wide compensated temperature ranges of -10~+60°C

Dimensions:



Specifications:

measuring ranges & type	bar, G	0/10, 0/16, 0/25, 0/35, 0/50, 0/100, 0/250, 0/300, 0/350, 0/400, 0/700
overload pressure	% FS	150
signal output@FS	mV/V	2, 3, 3.33
or: amplified signal output		0~5 Vdc, 0~10 Vdc, 4~20 mA
combined error	% FS	0.5 (typical), 1.0 (max.)
zero balance	% FS	± 1%
repeatability	% FS	0.2
input resistance	Ω	350 ±10% or 1000 ± 10% (for mV output transducers)
output resistance	Ω	350 ±10% or 1000 ± 10% (for mV output transducers)
insulation resistance	MΩ	≥500 @ 100 Vdc
supply voltage		10 V, 12 V (max.), for transducers with mV output signal
		24 V dc (typical), for transducers with amplified output signal
temperature effect on ZERO	% FS/10°C	0.5
temperature effect on SPAN	% FS/10°C	0.5
long term stability	% FS/year	<0.15
working temperature range	°C	-40 ~ 125
compensated temperature range	°C	-10 ~ 60
process connection		1/2"-20 UNF (standard), 7/16"-20 UNF, 1/4" NPT, M16x1.5, M20x1.5
electrical connection		4-pin (standard), 5-pin, 6-pin connector, shield PVC cable, hirschmann connector

The listed specifications are subject to change without pre-notice.

How to order: model - range - pressure type - output - accuracy - electric connector

example: 326F - 0/50 - G - 4/20 mA - 0.5 %FS - hirschmann

BCM SENSOR TECHNOLOGIES

IndustriePark, Brechtsebaan 2
B-2900 Schoten (Antwerp), BELGIUM
Tel.: +32-3-238 6469
Fax: +32-3-238 4171
website: www.bcmsensor.com
email: sales@bcmsensor.com

Laser transducer

Smart Sensor Laser Sensor with Built-in Amplifier

ZX1

A CMOS Laser Sensor That's Optimum for Simple Measurements

- A resolution of 0.002 mm that's suitable for simple measurements.
- Stable measurements for any type of workpiece.
- Models available with four different distance specifications.
- Long-distance model for up to 1,000 mm.

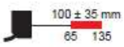
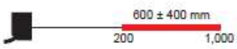
Refer to Safety Precautions on page 4.

This datasheet contains information only for selecting the appropriate model.
Be sure to read the instruction sheet for usage precautions prior to using the product.

CE

Ordering Information

Sensors (Refer to Dimensions on page 5.)

Appearance	Connection method	Cable length	Sensing distance	Model	
				NPN output	PNP output
	Pre-wired	2 m		ZX1-LD50A61 2M *	ZX1-LD50A81 2M *
		5 m		ZX1-LD50A61 5M	ZX1-LD50A81 5M
	Pre-wired connector	0.5 m		ZX1-LD50A66 0.5M	ZX1-LD50A86 0.5M
	Pre-wired	2 m		ZX1-LD100A61 2M *	ZX1-LD100A81 2M *
		5 m		ZX1-LD100A61 5M	ZX1-LD100A81 5M
	Pre-wired connector	0.5 m		ZX1-LD100A66 0.5M	ZX1-LD100A86 0.5M
	Pre-wired	2 m		ZX1-LD300A61 2M *	ZX1-LD300A81 2M *
		5 m		ZX1-LD300A61 5M	ZX1-LD300A81 5M
	Pre-wired connector	0.5 m		ZX1-LD300A66 0.5M	ZX1-LD300A86 0.5M
	Pre-wired	2 m		ZX1-LD600A61 2M *	ZX1-LD600A81 2M *
		5 m		ZX1-LD600A61 5M	ZX1-LD600A81 5M
	Pre-wired connector	0.5 m		ZX1-LD600A66 0.5M	ZX1-LD600A86 0.5M

* Sensors with Class 1 lasers are also available.
Add an "L" to the end of the model number when ordering. (Example: ZX1-LD50A61L 2M)

Accessories (sold separately)

Extension Cables for Pre-wired Connector Models

An Extension Cable is not provided with the Sensor. Order an Extension Cable separately.
(Refer to Dimensions on page 6.)

Cable length	Model
10 m	ZX0-XC10R
20 m	ZX0-XC20R

Mounting Brackets

A Mounting Bracket is not provided with the Sensor. Order a Mounting Bracket separately if required.
(Refer to Dimensions on page 6.)

Applicable sensors	Appearance	Model	Remarks
ZX1-LD50☐ ZX1-LD100☐		E39-L180	Mounting Bracket: 1 Nut plate: 1 Phillips screws (M3×30): 2
ZX1-LD300☐ ZX1-LD600☐		E39-L181	Mounting Bracket: 1 Nut plate: 1 Phillips screws (M4×35): 2

1

ZX1

Ratings and Specifications

Item	Model					
	NPN output		ZX1-LD50A61 ZX1-LD50A66	ZX1-LD100A61 ZX1-LD100A66	ZX1-LD300A61 ZX1-LD300A66	ZX1-LD600A61 ZX1-LD600A66
	PNP output		ZX1-LD50A81 ZX1-LD50A86	ZX1-LD100A81 ZX1-LD100A86	ZX1-LD300A81 ZX1-LD300A86	ZX1-LD600A81 ZX1-LD600A86
Measurement range			50 ± 10 mm	100 ± 35 mm	300 ± 150 mm	600 ± 400 mm
Light source (wave length)			Visible-light semiconductor laser (wavelength: 660 nm, 1 mW max., IEC/EN Class 2, FDA Class 2 *1)			
Spot diameter (typical) (Defined at the measurement center distance) *2			0.17 mm dia.	0.33 mm dia.	0.52 mm dia.	0.56 mm dia.
Power consumption			2,500 mW max. (105 mA max. at 24 VDC, 210 mA max. at 12 VDC)			
Current consumption			250 mA max. (at power supply voltage 10 VDC)			
Control output			Load power supply voltage: 30 VDC max., Load current: 100 mA max. (Residual voltage: 1 V max. (load current 10 mA or less), 2 V max. (load current of 10 to 100 mA))			
Analog output			Current output: 4 to 20 mA, maximum load resistance: 300 Ω			
Functions			Smart tuning, keep function, background removal, OFF-delay timer, ON-delay timer, one-shot timer, ON/OFF-delay timer, zero reset, area output, eco function, hysteresis width setting, and setting initialization			
Indicators			Digital display (red), output indicator (OUT1, OUT2) (orange), zero reset indicator (orange), menu indicator (orange), laser ON indicator (green), and smart tuning indicator (blue)			
Response time	Judgment output		Super-high-speed (SHS) Mode: 1 ms High-speed (HS) Mode: 10 ms Standard (Stnd) Mode : 100 ms			
	Laser OFF input		200 ms max.			
	Zero reset input		200 ms max.			
Temperature characteristic *3			0.03% F.S./°C			0.04% F.S./°C
Linearity *4			±0.15% F.S.		±0.25% F.S.	±0.25% F.S. (200 to 600 mm) ±0.5% F.S. (entire range)
Resolution *5			2 µm	7 µm	30 µm	80 µm
Ambient illumination			Illumination on received light surface: 7,500 lx or less (incandescent light)		Illumination on received light surface: 5,000 lx or less (incandescent light)	
Ambient temperature			Operating: -10 to +55°C, Storage: -15 to +70°C (with no icing or condensation)			
Ambient humidity			Operating and storage: 35% to 85% (with no condensation)			
Dielectric strength			1,000 VAC, 50/60 Hz, 1 minute			
Vibration resistance (destruction)			10 to 55 Hz, 1.5-mm double amplitude, 2 hours each in X, Y, and Z directions			
Shock resistance (destruction)			500 m/s² 3 times each in X, Y, and Z directions			
Degree of protection *6			IEC 60529, IP67			
Connection method *7			Pre-wired model (Standard cable length: 2 m, 5 m) Pre-wired connector model (Standard cable length: 0.5 m)			
Weight (packed state/ sensor only)	Pre-wired models (2 m)		Approx. 240 g / Approx. 180 g		Approx. 270 g / Approx. 210 g	
	Pre-wired models (5 m)		Approx. 450 g / Approx. 330 g		Approx. 480 g / Approx. 360 g	
	Pre-wired connector models (0.5 m)		Approx. 170 g / Approx. 110 g		Approx. 200 g / Approx. 140 g	
Materials			Case and cover: PBT (polybutylene terephthalate), Optical window: Glass, Cable: PVC, Mounting hole part: SUS303			
Accessories			Instruction sheet and Laser warning label (English)			

Note: 1. False detection outside the measurement range can occur in the case of an object with high reflectance.
2. **Refer to the next page for the ratings and specifications of Sensors with Class 1 lasers.**

*1. Classified as Class 2 by IEC60825-1 criteria in accordance with the FDA standard previsions of Laser Notice No. 50. CDRH registration has been completed. (Center for Devices and Radiological Health) (Accession Number: 1210041)

*2. Spot diameter: Defined as $1/e^2$ (13.5%) of the central intensity at the measurement center distance.
False detections can occur in the case there is light leakage outside the defined region and the surroundings of the target object have a high reflectance in comparison to the target object.
Accurate measurements may not be possible for workpieces that are smaller than the spot diameter.

*3. Temperature characteristic: Value for the case the space between the sensor and Omron's standard target object is secured by an aluminum jig. (Measured at the measurement center distance)

*4. Linearity: Indicates the error with respect to the ideal straight line of the displacement output in the case of measuring Omron's standard target object (white ceramic) at a temperature of 25 °C.
Linearity and measured value may vary depending on target object.

*5. Resolution: Defined in Standard Mode for Omron's standard target object (white ceramic) after executing Smart Tuning.
The resolution indicates the repetition accuracy for a still workpiece. Not an indication of the distance accuracy.
Resolution performance may not be satisfied in a strong electromagnetic field.

*6. IP67 protection applies to the connector on pre-wired connector models if an extension cable is connected.

*7. Use a Pre-wired Connector Model together with an Extension Cable (10 m or 20 m).

Ratings and Specifications of Sensors with Class 1 lasers (ZX1-LD□L)

The ratings and specifications that are different from those of the Sensors with Class 2 lasers are given below.

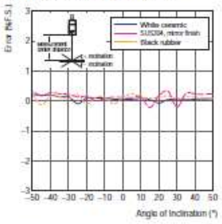
Item \ Model	ZX1-LD50A61L/ZX1-LD50A81L ZX1-LD100A61L/ZX1-LD100A81L	ZX1-LD300A61L/ZX1-LD300A81L ZX1-LD600A61L/ZX1-LD600A81L
FDA Class	Class1 0.24mW max.	
IEC/EN Class	Class1 0.24mW max.	
Ambient illumination	Illumination on received light surface 5,000 lx or less (incandescent light)	Illumination on received light surface 2,500 lx or less (incandescent light)
Connection method	Pre-wired model (2 m)	
Accessories	Instruction sheet and Explanatory label (English), FDA certification label	

Accession Number: 1210041

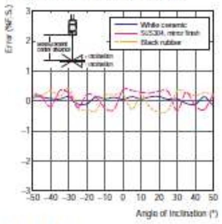
Engineering Data (Typical)

Angle Characteristic

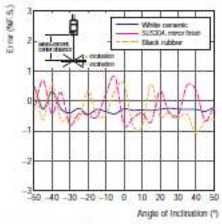
ZX1-LD50□
Side-to-side Inclination



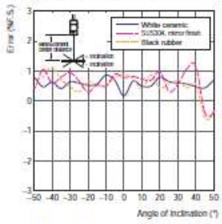
ZX1-LD100□
Side-to-side Inclination



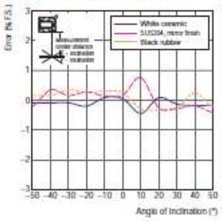
ZX1-LD300□
Side-to-side Inclination



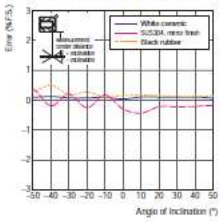
ZX1-LD600□
Side-to-side Inclination



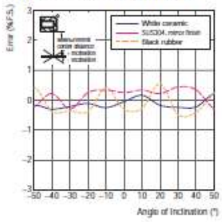
ZX1-LD50□
Front-to-back Inclination



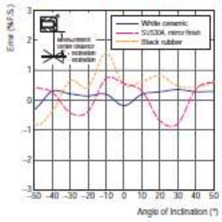
ZX1-LD100□
Front-to-back Inclination



ZX1-LD300□
Front-to-back Inclination

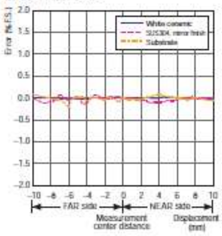


ZX1-LD600□
Front-to-back Inclination

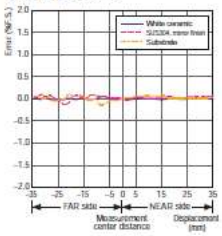


Linearity Characteristic for Different Materials

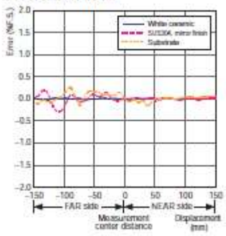
ZX1-LD50□



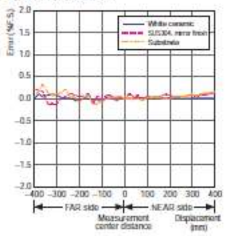
ZX1-LD100□



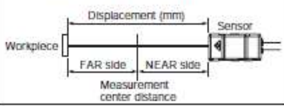
ZX1-LD300□



ZX1-LD600□



Measurement diagram



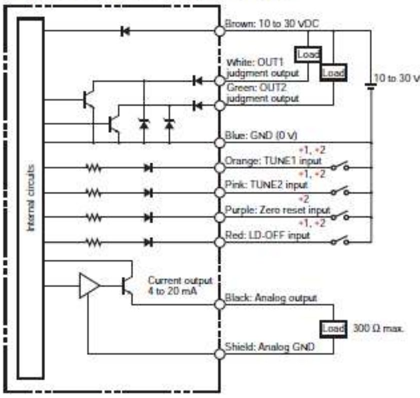
Note: 1. Measurement conditions for the ZX1-LD□□: Ambient temperature of 25°C in Standard Mode after executing Smart Tuning.
2. The ambient conditions or workpiece may adversely affect the engineering data of the ZX1-LD□L.
3. The X-axis displacement indicates the measurement distance displayed on a digital display.
The measurement distance displayed on a digital display takes the measurement center distance as 0 and displays the near side of the Sensor as positive and the far side as negative.

ZX1

I/O Circuit Diagrams

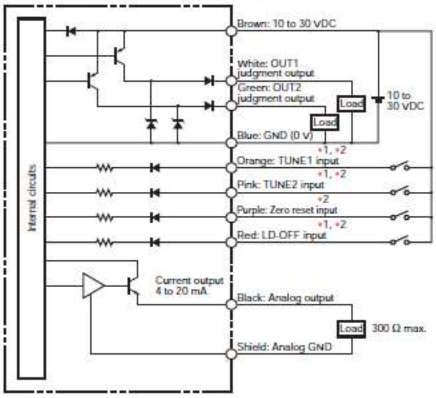
NPN Output Model (Negative Common)

ZX1-LD50A61(L) /ZX1-LD50A66
ZX1-LD100A61(L) /ZX1-LD100A66
ZX1-LD300A61(L) /ZX1-LD300A66
ZX1-LD600A61(L) /ZX1-LD600A66



PNP Output Model (Positive Common)

ZX1-LD50A81(L) /ZX1-LD50A86
ZX1-LD100A81(L) /ZX1-LD100A86
ZX1-LD300A81(L) /ZX1-LD300A86
ZX1-LD600A81(L) /ZX1-LD600A86



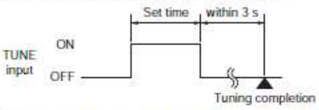
*1. TUNE1 input: tuning external input for channel 1
TUNE2 input: tuning external input for channel 2
LD-OFF input: Laser OFF input
*2. The input specification is as follows:

	NPN Output Model	PNP Output Model
ON	Short-circuited with 0-V terminal or 1.5 V max.	Supply voltage short-circuited or supply voltage within -1.5 V
OFF	Open (leakage current: 0.1 mA max.)	Open (leakage current: 0.1 mA max.)

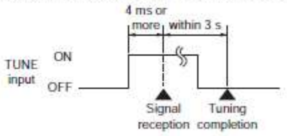
Timing Charts

TUNE1 Input / TUNE2 Input

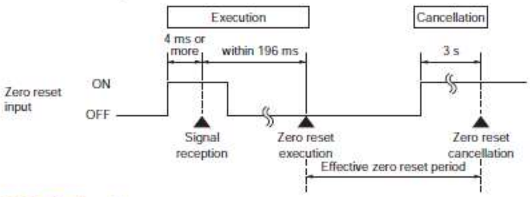
(1) Time identification tuning type



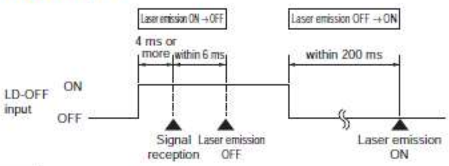
(2) Tuning type other than time identification



Zero Reset Input



LD-OFF Input



Safety Precautions

This datasheet contains information only for selecting the appropriate model.
Be sure to read the Instruction Sheet for usage precautions prior to using the product.

Laser Safety

⚠ WARNING

ZX1-LD□□□: Class 2, ZX1-LD□□□L: Class1

Do not expose your eyes to the laser radiation either directly or indirectly (i.e., after reflection from a mirror or shiny surface).
The laser radiation has a high power density and exposure may result in loss of sight.

Do not disassemble the product.
Doing so may cause the laser beam to leak, resulting in the danger of visual impairment.

Note: For Precautions for safe use and Precautions for correct use, refer to the Instruction Sheet supplied with the product.

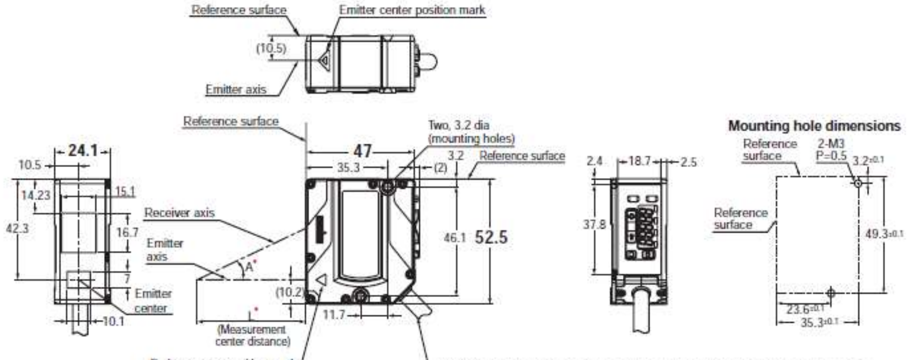
Dimensions

(Unit: mm)
Tolerance class IT16 applies to dimensions in this datasheet unless otherwise specified.

Sensors

Pre-wired Models
ZX1-LD50A61(L)
ZX1-LD50A81(L)
ZX1-LD100A61(L)
ZX1-LD100A81(L)

Pre-wired Connector Models
ZX1-LD50A66
ZX1-LD50A86
ZX1-LD100A66
ZX1-LD100A86

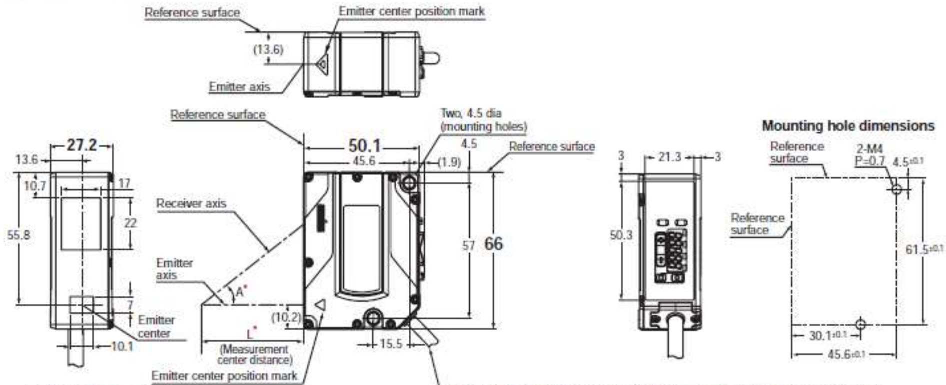


*ZX1-LD50: L = 50, A = 21°
ZX1-LD100: L = 100, A = 11.5°

Vinyl insulated round robot cable, 6.5 dia., 9 conductors (Conductor cross section: 0.125 mm², Insulator diameter: 0.7 mm)
Standard length: 2 m / 5 m (pre-wired model), 0.5 m (pre-wired connector model)
Minimum bending radius: 39 mm

Pre-wired Models
ZX1-LD300A61(L)
ZX1-LD300A81(L)
ZX1-LD600A61(L)
ZX1-LD600A81(L)

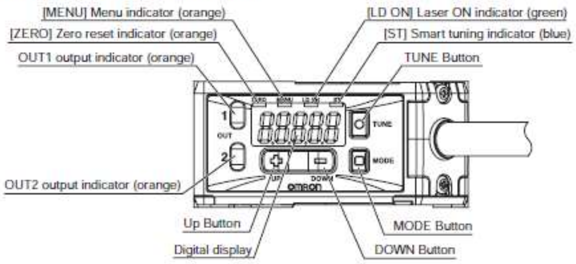
Pre-wired Connector Models
ZX1-LD300A66
ZX1-LD300A86
ZX1-LD600A66
ZX1-LD600A86



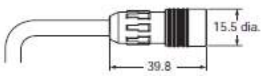
*ZX1-LD300: L = 300, A = 6.6°
ZX1-LD600: L = 600, A = 3.4°

Vinyl insulated round robot cable, 6.5 dia., 9 conductors (Conductor cross section: 0.125 mm², Insulator diameter: 0.7 mm)
Standard length: 2 m / 5 m (pre-wired model), 0.5 m (pre-wired connector model)
Minimum bending radius: 39 mm

Display, Indicators, and Controls



Pre-wired connector



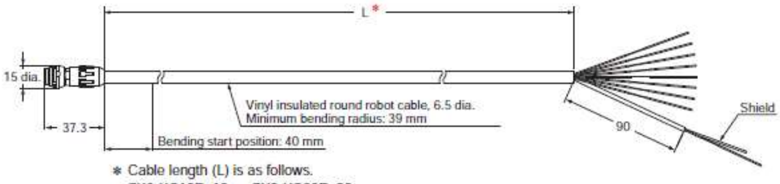
5

ZX1

Accessories (sold separately)

Extension Cables for Pre-wired Connector Models

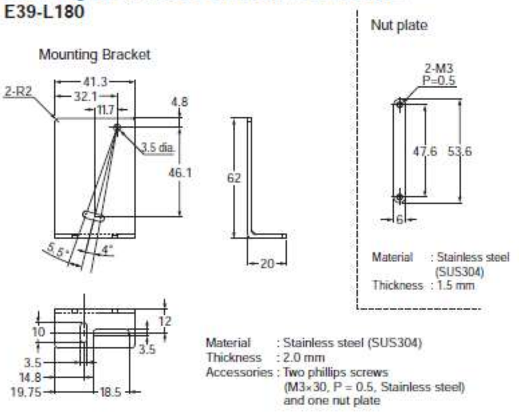
ZX0-XC10R (10 m)
ZX0-XC20R (20 m)



* Cable length (L) is as follows.
ZX0-XC10R: 10 m, ZX0-XC20R: 20 m

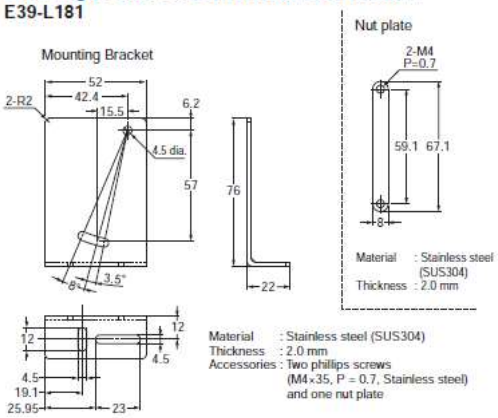
Mounting Bracket for ZX1-LD50□/ZX1-LD100□

E39-L180



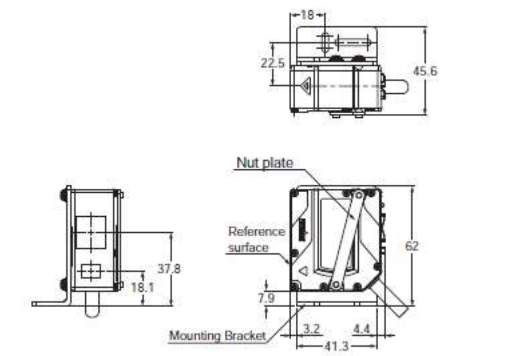
Mounting Bracket for ZX1-LD300□/ZX1-LD600□

E39-L181



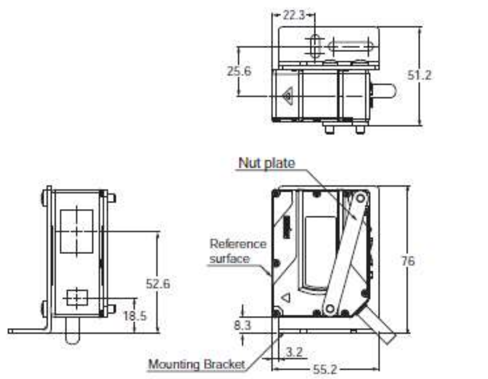
Installation Method (ZX1-LD50□/ZX1-LD100□)

Using E39-L180 Mounting Bracket



Installation Method (ZX1-LD300□/ZX1-LD600□)

Using E39-L181 Mounting Bracket



6

OMRON

READ AND UNDERSTAND THIS DOCUMENT

Please read and understand this document before using the products. Please consult your OMRON representative if you have any questions or comments.

WARRANTY

OMRON's exclusive warranty is that the products are free from defects in materials and workmanship for a period of one year (or other period if specified) from date of sale by OMRON.

OMRON MAKES NO WARRANTY OR REPRESENTATION, EXPRESS OR IMPLIED, REGARDING NON-INFRINGEMENT, MERCHANTABILITY, OR FITNESS FOR PARTICULAR PURPOSE OF THE PRODUCTS. ANY BUYER OR USER ACKNOWLEDGES THAT THE BUYER OR USER ALONE HAS DETERMINED THAT THE PRODUCTS WILL SUITABLY MEET THE REQUIREMENTS OF THEIR INTENDED USE. OMRON DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED.

LIMITATIONS OF LIABILITY

OMRON SHALL NOT BE RESPONSIBLE FOR SPECIAL, INDIRECT, OR CONSEQUENTIAL DAMAGES, LOSS OF PROFITS OR COMMERCIAL LOSS IN ANY WAY CONNECTED WITH THE PRODUCTS, WHETHER SUCH CLAIM IS BASED ON CONTRACT, WARRANTY, NEGLIGENCE, OR STRICT LIABILITY.

In no event shall responsibility of OMRON for any act exceed the individual price of the product on which liability is asserted.

IN NO EVENT SHALL OMRON BE RESPONSIBLE FOR WARRANTY, REPAIR, OR OTHER CLAIMS REGARDING THE PRODUCTS UNLESS OMRON'S ANALYSIS CONFIRMS THAT THE PRODUCTS WERE PROPERLY HANDLED, STORED, INSTALLED, AND MAINTAINED AND NOT SUBJECT TO CONTAMINATION, ABUSE, MISUSE, OR INAPPROPRIATE MODIFICATION OR REPAIR.

SUITABILITY FOR USE

THE PRODUCTS CONTAINED IN THIS DOCUMENT ARE NOT SAFETY RATED. THEY ARE NOT DESIGNED OR RATED FOR ENSURING SAFETY OF PERSONS, AND SHOULD NOT BE RELIED UPON AS A SAFETY COMPONENT OR PROTECTIVE DEVICE FOR SUCH PURPOSES. Please refer to separate catalogs for OMRON's safety rated products.

OMRON shall not be responsible for conformity with any standards, codes, or regulations that apply to the combination of products in the customer's application or use of the product.

At the customer's request, OMRON will provide applicable third party certification documents identifying ratings and limitations of use that apply to the products. This information by itself is not sufficient for a complete determination of the suitability of the products in combination with the end product, machine, system, or other application or use.

The following are some examples of applications for which particular attention must be given. This is not intended to be an exhaustive list of all possible uses of the products, nor is it intended to imply that the uses listed may be suitable for the products:

- Outdoor use, uses involving potential chemical contamination or electrical interference, or conditions or uses not described in this document.
- Nuclear energy control systems, combustion systems, railroad systems, aviation systems, medical equipment, amusement machines, vehicles, safety equipment, and installations subject to separate industry or government regulations.
- Systems, machines, and equipment that could present a risk to life or property.

Please know and observe all prohibitions of use applicable to the products.

NEVER USE THE PRODUCTS FOR AN APPLICATION INVOLVING SERIOUS RISK TO LIFE OR PROPERTY WITHOUT ENSURING THAT THE SYSTEM AS A WHOLE HAS BEEN DESIGNED TO ADDRESS THE RISKS, AND THAT THE OMRON PRODUCT IS PROPERLY RATED AND INSTALLED FOR THE INTENDED USE WITHIN THE OVERALL EQUIPMENT OR SYSTEM.

PERFORMANCE DATA

Performance data given in this document is provided as a guide for the user in determining suitability and does not constitute a warranty. It may represent the result of OMRON's test conditions, and the users must correlate it to actual application requirements. Actual performance is subject to the OMRON Warranty and Limitations of Liability.

CHANGE IN SPECIFICATIONS

Product specifications and accessories may be changed at any time based on improvements and other reasons.

It is our practice to change model numbers when published ratings or features are changed, or when significant construction changes are made. However, some specifications of the product may be changed without any notice. When in doubt, special model numbers may be assigned to fix or establish key specifications for your application on your request. Please consult with your OMRON representative at any time to confirm actual specifications of purchased products.

DIMENSIONS AND WEIGHTS

Dimensions and weights are nominal and are not to be used for manufacturing purposes, even when tolerances are shown.

ERRORS AND OMISSIONS

The information in this document has been carefully checked and is believed to be accurate; however, no responsibility is assumed for clerical, typographical, or proofreading errors, or omissions.

PROGRAMMABLE PRODUCTS

OMRON shall not be responsible for the user's programming of a programmable product, or any consequence thereof.

COPYRIGHT AND COPY PERMISSION

This document shall not be copied for sales or promotions without permission.

This document is protected by copyright and is intended solely for use in conjunction with the product. Please notify us before copying or reproducing this document in any manner, for any other purpose. If copying or transmitting this document to another, please copy or transmit it in its entirety.

ALL DIMENSIONS SHOWN ARE IN MILLIMETERS.
To convert millimeters into inches, multiply by 0.03937. To convert grams into ounces, multiply by 0.03527.

OMRON Corporation **Industrial Automation Company**
Tokyo, JAPAN

Contact: www.ia.omron.com

Regional Headquarters
OMRON EUROPE B.V.
Sensor Business Unit
Carl-Benz-Str. 4, D-71154 Nufringen, Germany
Tel: (49) 7032-811-0/Fax: (49) 7032-811-199

OMRON ELECTRONICS LLC
One Commerce Drive Schaumburg,
IL 60173-5302 U.S.A.
Tel: (1) 847-843-7900/Fax: (1) 847-843-7787

OMRON ASIA PACIFIC PTE. LTD.
No. 438A Alexandra Road # 05-05/08 (Lobby 2),
Alexandra Technopark,
Singapore 119967
Tel: (65) 6835-3011/Fax: (65) 6835-2711

OMRON (CHINA) CO., LTD.
Room 2211, Bank of China Tower,
200 Yin Cheng Zhong Road,
PuDong New Area, Shanghai, 200120, China
Tel: (86) 21-5037-2222/Fax: (86) 21-5037-2200

Authorized Distributor:

CSM_1_6_0213
Cat. No. E416-E1-02
Printed in Japan
0112(1111)

Appendix C – Data collection

Technical Sales
Australia
1 800 300 800
info.australia@ni.com

NI USB-9215A

Portable USB-Based DAQ With Simultaneous Sampling

- For new designs, NI recommends the NI 9215 Measurement Bundle
- Plug-and-play connectivity via USB
- Sampling rates at 100 kS/s per channel
- Small, portable devices (12.1 x 8.6 x 2.5 cm)
- Includes NI-DAQmx driver software and NI LabVIEW SignalExpress LE for Windows
- Includes NI-DAQmx Base driver software for Linux and Mac

Overview

The NI USB-9215A DAQ module features integrated signal conditioning that provides plug-and-play connectivity via USB for faster setup and measurements. It offers four channels of simultaneously sampled voltage inputs with 16-bit accuracy to provide minimal phase delay when scanning multiple channels. With both screw terminal and BNC connector options, the USB-9215A is designed for flexible and low-cost signal wiring. In addition, this module includes 250 Vrms channel-to-earth ground isolation for safety, noise immunity, and high common-mode voltage range.

The USB-9215A is compatible with Windows OSs when using NI-DAQmx driver software, and Mac OS X and Linux OSs when using NI-DAQmx Base driver software. This USB DAQ module is not compatible with the Traditional NI-DAQ (Legacy) driver.

Every NI USB DAQ module includes a copy of LabVIEW SignalExpress LE for Windows so you can quickly acquire, analyze, and present data without programming. In addition to LabVIEW SignalExpress, USB DAQ modules are compatible with the following versions (or later) of NI application software: LabVIEW 7.x, LabWindows™/CVI 7.x, or Measurement Studio 7.x; or LabVIEW with the LabVIEW Real-Time Module 7.1. USB DAQ modules are also compatible with ANSI C/C++, C#, Visual Studio .NET, and Visual Basic 6.0.

Services

Extended Warranties

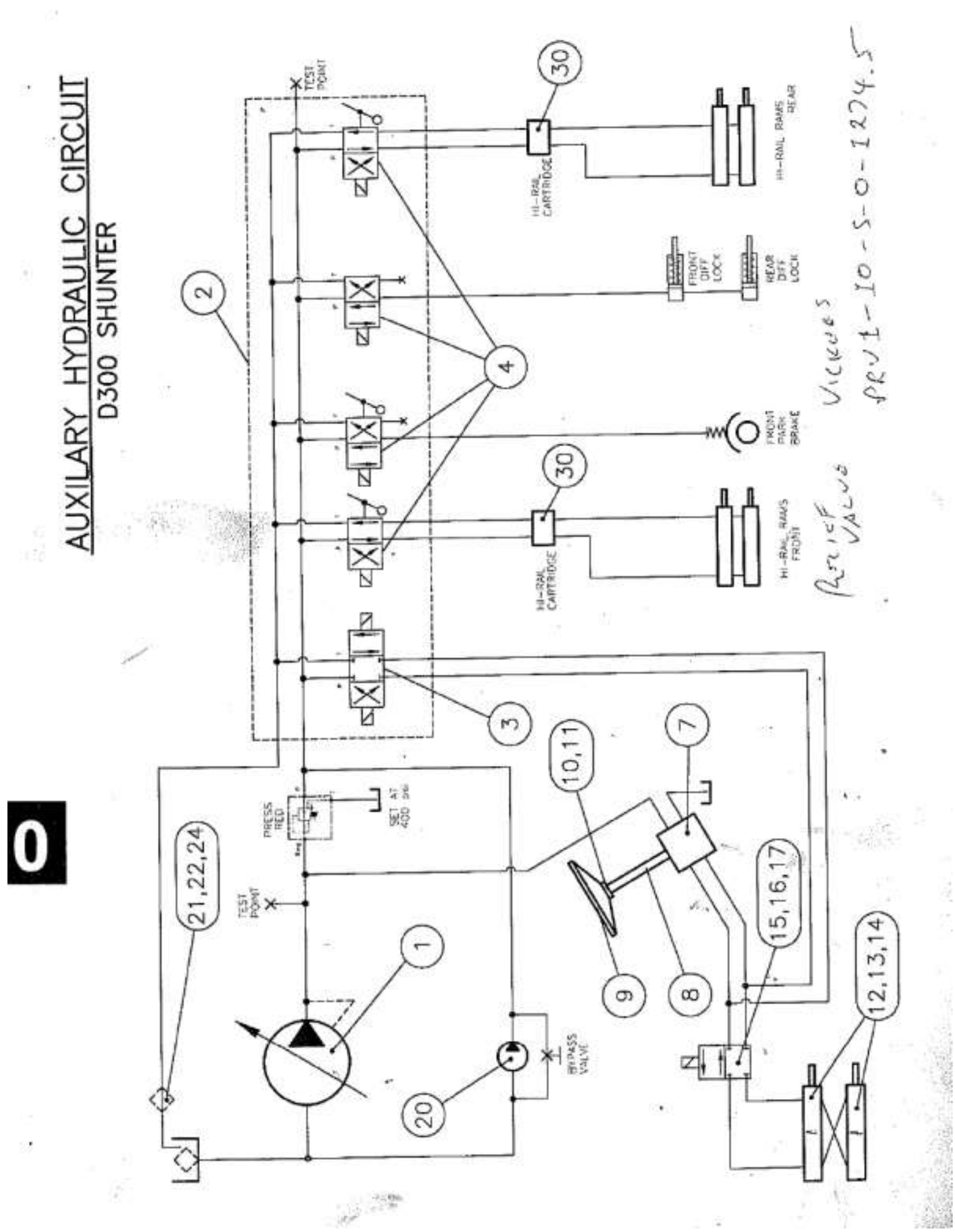
National Instruments designs and manufactures all products to minimize failures, however unexpected failures can still occur. Extended warranties provide a fixed economical price at the time of system purchase, covering any repair costs for up to three years. In addition, they offer the following benefits:

- Significant cost savings compared to individual repair incidents
- Fault location, diagnostics, and repair by NI any time the system product fails
- All parts and labor costs covered as well as any adjustments needed to restore the hardware to manufacturing specifications

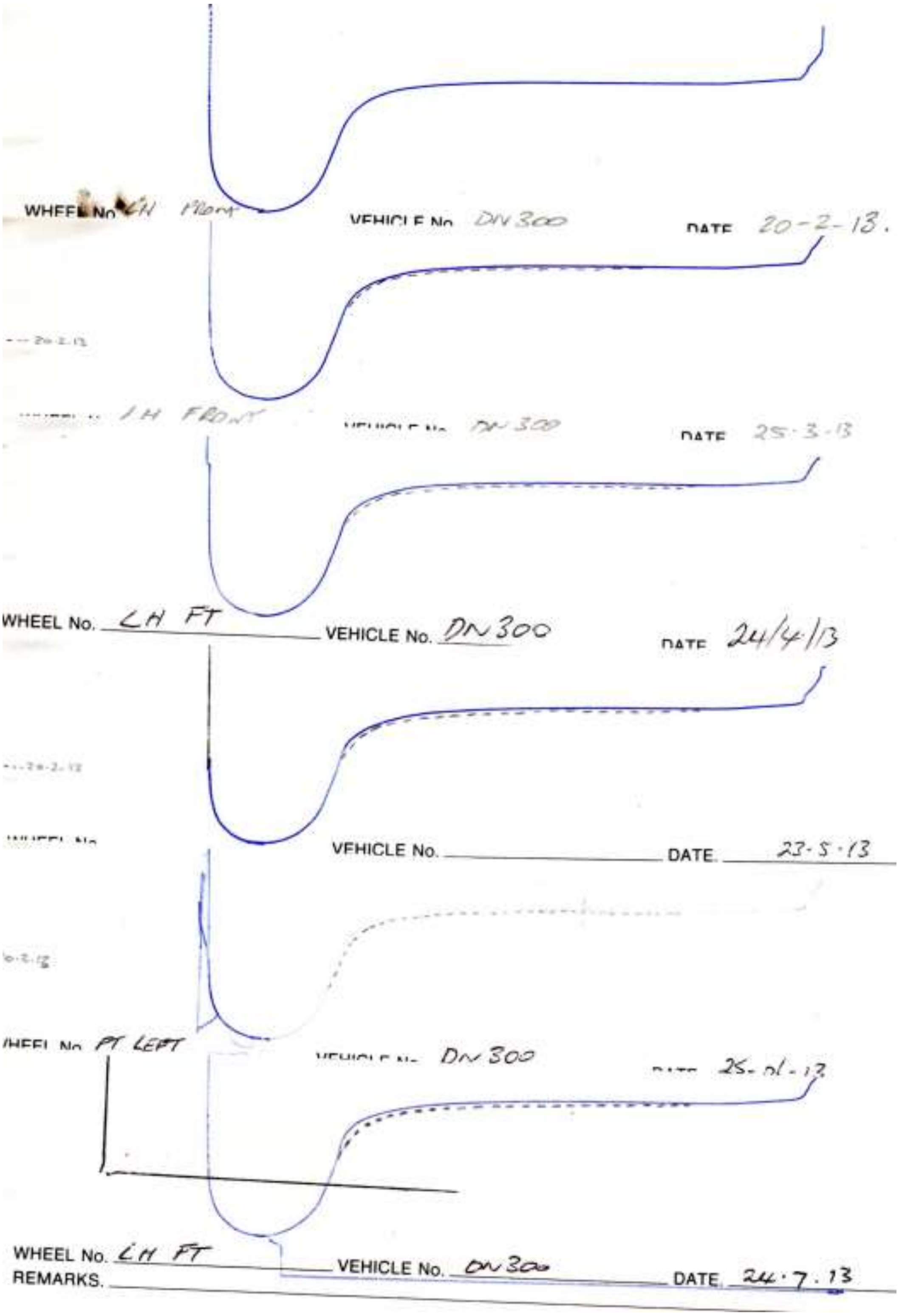
For more information about your warranty options:

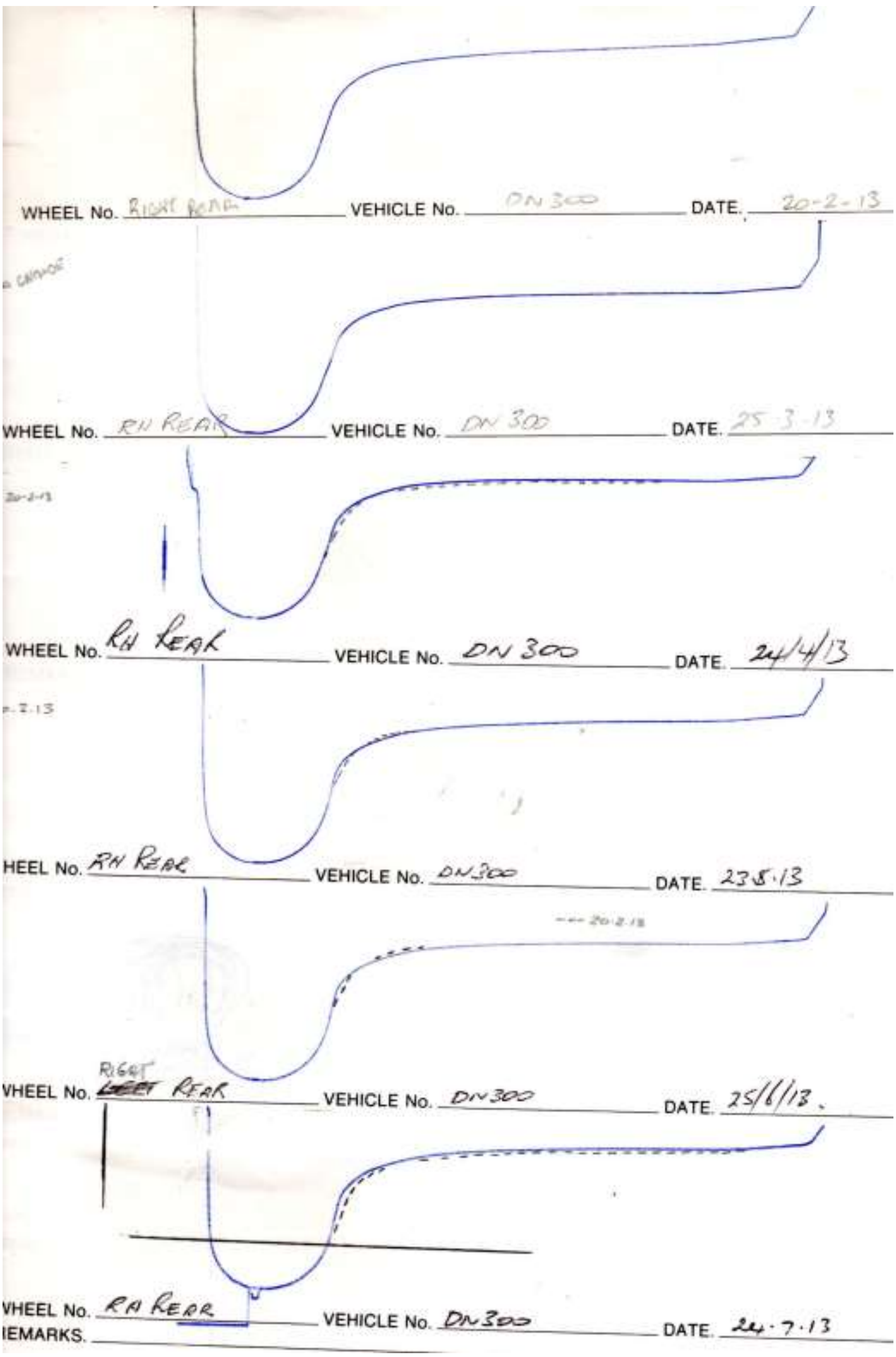
Appendix D – Hydraulic circuit

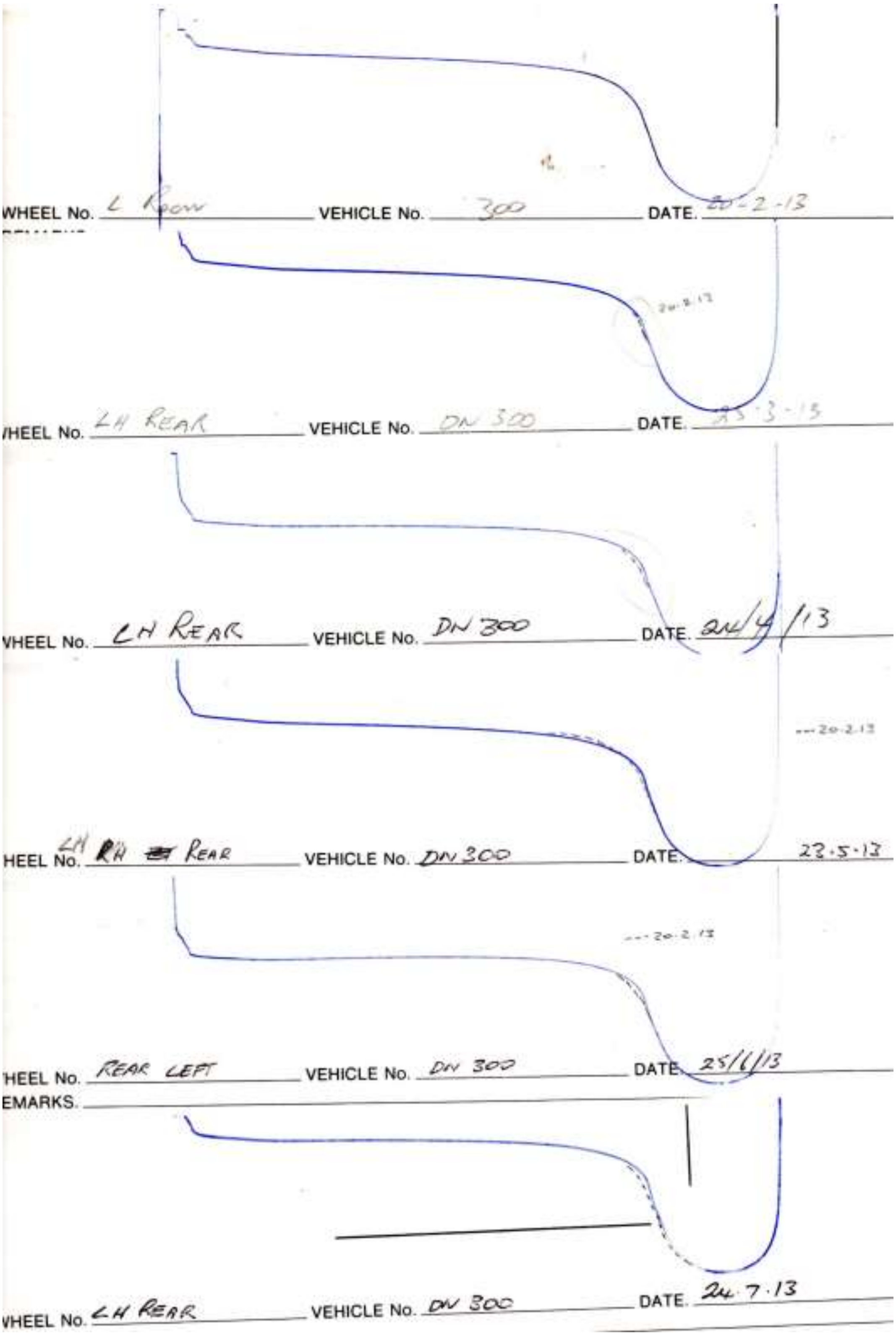
DN300 ROAD/RAIL SHUNTER PARTS & SERVICE MANUAL



Appendix E – Tread/flange profiles




WHEEL No. RIGHT REAR VEHICLE No. DN 300 DATE. 20-2-13
WHEEL No. RH REAR VEHICLE No. DN 300 DATE. 25-3-13
20-2-13
WHEEL No. RH REAR VEHICLE No. DN 300 DATE. 24/4/13
HEEL No. RH REAR VEHICLE No. DN300 DATE. 23.5.13
--- 20.2.13
VHEEL No. RIGHT REAR VEHICLE No. DN300 DATE. 25/6/13.
VHEEL No. RH REAR VEHICLE No. DN300 DATE. 24.7.13
IEMARKS.


WHEEL No. VEHICLE No. 300 DATE. 20-2-13
20-2-13
WHEEL No. LH REAR VEHICLE No. DN 300 DATE. 25-3-13
WHEEL No. LH REAR VEHICLE No. DN 300 DATE. 24/4/13
20-2-13
WHEEL No. LH RH REAR VEHICLE No. DN 300 DATE. 23-5-13
20-2-13
WHEEL No. REAR LEFT VEHICLE No. DN 300 DATE. 25/6/13
REMARKS.
WHEEL No. LH REAR VEHICLE No. DN 300 DATE. 24.7.13

Appendix F – Hydraulic oil analysis results

OIL ANALYSIS REPORT

LEGEND

Ag - Silver (bearings); **Al** - Aluminium (Pistons/Bearings); **Cr** - Chromium (rings); **Cu** - Copper (bearings); **Fe** - Iron (Wide range of parts e.g. Crankshaft); **Sn** - Tin (Bearings)
Zn - Zinc (Additive); **Mo** - Molybdenum (Additive); **Na** - Sodium (Additive and Coolant); **Ni** - Nickel (Bearings); **Pb** - Lead (Petrol additive/Bearings); **Si** - Silicon (Dirt/Sealant)
All elemental concentrations expressed as milligrams per kilograms (mg/kg)

RATINGS: **5**: VERY GOOD, **4**: GOOD, **3**: SATISFACTORY, **2**: WARNING, **1**: ALERT

Unit	Compartment	Sample Date	Depot	Rating	Viscosity (cSt)	Ag (mg/kg)	Al (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mo (mg/kg)	Na (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Si (mg/kg)	Sn (mg/kg)	Zn (mg/kg)	Sediment	Oxidant	Water (%)	TAN	Oil	Oil Changed	Machine Hours
DN300	HYDRAULIC	12/8/2013	ROCKHAMPTON	3	68	0.3	1	0.6	3	12	0	0	0.6	3	6	0.7	52	18/11	19	0	0.18	HV 68	FALSE	

Oil & wear condition appear satisfactory

Appendix G – Risk assessment

THE FITMENT OF MONITORING EQUIPMENT TO THE D & N SHUNT VEHICLES AND THE SUBSEQUENT ON TRACK TRIALS

Note 1: *The original of this document, duly signed by the treatment owner and authorising officer, is held by the Document Controller within the Office of the Vice President Engineering Services.*
Note 2: *This document is for the sole use of Engineering Services Staff, and shall not be distributed to others without the prior approval of the Vice President Engineering Services.*

1. REFERENCE DOCUMENTS:

The following sources of reference material have been used to develop this document:

Reference No.	Document Title
PRI/0014/COR	Safety Risk Management
AS/NZS ISO 31000:2009	Risk Management – Principles and Guidelines
RR-01	Engineering Services Hazard and Safety Risk Register
RMT/DIR/0001	Risk Management Framework

Aurizon's Five Safety Principles

1. Safety is the core Aurizon value
2. All injuries can be prevented
3. Management is accountable for creating & maintaining a safe workplace
4. We are ALL responsible for preventing injuries
5. Working safely is a condition of employment

2. RISK ASSESSMENT CONTEXT

Risk Assessment Forum	**On site meeting with concerned parties**
Risk Scope & Context (Purpose)	**The objective of this risk assessment is to quantify the risks associated with fitting monitoring equipment (displacement transducers, pressure transducer and cameras) to the D & N shunt vehicles and the subsequent operation of the vehicles with the monitoring equipment attached.**
Background	**There have been a number of derailments of the D & N shunt vehicles within the RM Rockhampton yard so monitoring equipment is to be fitted to log the vehicle operations in an effort to find the root cause of the derailments.**
Review Date	

Facilitator:	
Chris Langes Technical Officer Engineering Services	
Attendees at risk assessment meeting:	
Peter Williams Snr Elect Eng Engineering Solutions	<Name> <Title> <Business Group>
Simon Law Engineering Trades Person Operations	<Name> <Title> <Business Group>
Zane Hooton Production Support Manager Operations	<Name> <Title> <Business Group>
Darren Brehmer Qld Field Support Officer Engineering Solutions	<Name> <Title> <Business Group>
<Name> <Title> <Business Group>	<Name> <Title> <Business Group>

Consultation:
<Name> <Title> <Business Group>
<Name> <Title> <Business Group>
<Name> <Title> <Business Group>
<Name> <Title> <Business Group>
<Name> <Title> <Business Group>
<Name> <Title> <Business Group>
<Name> <Title> <Business Group>

3. SAFETY RISK ASSESSMENT (CONDUCTED IN ACCORDANCE WITH PRI/0014/COR – SAFETY RISK MANAGEMENT)

Note 3: When conducting the Safety Risk Assessment, reference should be first made to the current Engineering Services Hazard and Safety Risk Register, to identify any Hazards/Safety Risks that have been previously approved by the relevant Level of Authority required by PRI/0014/COR. Hazards/Safety Risks identified from the register shall be documented in this section.

Note 4: All Control Measures for each Hazard/Risk shall be identified as CM1, CM2, CM3…etc.

Note 5: Refer to PRI/0014/COR Safety Risk Management for determining the level of risk.

Note 6: The effectiveness of the implementation of all Control Measures shall be categorised in accordance with the following criteria:

5. Excellent	Effective treatments implemented, communicated and monitored on a regular basis to determine the level of effectiveness
4. Good	Well documented and implemented, but with some room for improvement. Good communication and understanding of treatments
3. Fair	In place, but not well implemented, documented or monitored to determine their level of relevance.
2. Marginal	Informal and inconsistent, not well communicated, implemented in an ad-hoc manner.
1. Poor or Non-Existent	Ineffective measures, not communicated, sparsely implemented and of little value.
0. Not Implemented	Control Measure is proposed but not yet implemented

Task / Activity / Objective (What is being achieved?):

If all the controls operate as intended and people follow the process as intended, has a safe working environment been created?:

Risk ID	Hazard *What is the primary source of harm?*	Inherent Risk Statement *What are the consequences that exist prior to any controls being put in place to manage that hazard?*	Controls	Control Level	Existing or Proposed Control?	Justification *Why is a higher order control not being applied? E.g. If Engineering, Administration, and PPE controls are being applied then why are there no Elimination, Substitution and Isolation controls being applied?*	Control effectiveness See note 6	Risk Level *The level of risk after consideration of existing controls only.*			Action Items *Task required to implement & monitor proposed treatment or monitor existing treatment.*	Accountable Officer *Who will carry out this task?*	Due Date *When is the task due?*
			Elimination	T1				C	L	Level of Risk			
			Substitution	T2									
			Isolation	T3									
			Engineering	T4									
			Administration	T5									
			PPE	T6									
1	Vehicle movement whilst fitting monitoring equipment	Possible crush injuries to workers, damage to plant and equipment	Vehicle to be parked on level ground and wheels to be chocked	T5	existing	Parking on level ground and choking of wheels is an effective method to prevent in advertent vehicle movement		3	1	4	Staff working on the fitting of monitoring equipment to the vehicle are to ensure wheels are chocked. Checksheet to be completed	All staff	Before commencing work on vehicle
2	Vehicle start up whilst fitting monitoring equipment	Possible inadvertent lifting of hi-rail wheels and articulation of machine	Remove keys and isolate battery at isolator. Place keys in lock box and all staff to place personal locks on box	T5	existing	Removing keys and isolating power source ensures there is no inadvertent start up		2	1	3	Staff working on the fitting of monitoring equipment to the vehicle are to ensure the power source is isolated. Checksheet to be completed	All staff	Before commencing work on vehicle

Task / Activity / Objective (What is being achieved?):

If all the controls operate as intended and people follow the process as intended, has a safe working environment been created?:

Risk ID	Hazard *What is the primary source of harm?*	Inherent Risk Statement *What are the consequences that exist prior to any controls being put in place to manage that hazard?*	Controls	Control Level	Existing or Proposed Control?	Justification *Why is a higher order control not being applied? E.g. If Engineering, Administration, and PPE controls are being applied then why are there no Elimination, Substitution and Isolation controls being applied?*	Control effectiveness *See note 6*	Risk Level *The level of risk after consideration of existing controls only.*			Action Items *Task required to implement & monitor proposed treatment or monitor existing treatment.*	Accountable Officer *Who will carry out this task?*	Due Date *When is the task due?*
3	Location of monitoring equipment on shunt vehicle	Possible interference with vehicle operation	Mount in positions that will not interfere with vehicle operation	T4	proposed	Require brackets to mount transducers in strategic locations	D	1	1	2	Sketch prepared by CL, check sheet to be completed	CL	
4	Laser displacement transducers	Eye injury from laser beam	AS 2397 – little hazard from class II laser – generally incapable of causing eye injury within the duration of the blink or aversion response.	T5	proposed	Laser transducer is more reliable transducer	D	2	1	3	Mount transducers to minimise reflections – as operation will be outdoors it is considered there will be little if any reflection of light. Check sheet to be completed	CL	
5	Fitting of brackets to shunt vehicle	Cramped conditions when fitting lower brackets	Raising of vehicle onto blocks to increase working space	T5	Proposed	Brackets are required to be mounted under vehicle	D	1	1	2	Vehicle to be raised if conditions are too cramped to work effectively to fit equipment. Check sheet to be completed.	CL	
6	Routing of cables from transducer locations to datalogging equipment in the vehicle cab	Pinching and chaffing of cables	Ensure cables are covered when resting on places where chaffing of cables is likely, use of bushing in all entry/exit holes	T5	proposed	Datalogger is to be mounted in the cab therefore cabling must be taken into cab	D	2	1	3	All cables to be protected where likely to rub. Check sheet to be completed following fitment	CL	
7	Possible flattening of vehicle battery with monitoring equipment connected	Unable to start vehicle	Ensure all equipment is isolated when vehicle is shut down for the day	T5	proposed	Power for monitoring equipment is to be taken from vehicle battery supply	D	2	1	3	Equipment to be isolated when not in use signage to be displayed on all equipment in the cab. Check sheet to be completed following fitment	CL	
8	Mounting bracket works loose	Loss of monitoring equipment, fall onto rail and may cause derailment	Use lock nuts on all hold down bolts	T5	proposed	Temporary brackets as monitoring is to be only a short term exercise	D	1	1	2	Check sheet to be completed following fitment		

4. BUSINESS RISK ASSESSMENT (CONDUCTED IN ACCORDANCE WITH RMT/DIR/0001 – ENTERPRISE RISK MANAGEMENT FRAMEWORK)

Note 7: All Control Measures for each Business Risk shall be identified as CM1, CM2, CM3....etc.
Note 8: If no Business Risks exists, or they are not relevant to the scope of this Risk Assessment, please document 'Nil' or 'Not Within the Scope of Assessment' in the Risk Statement.
Note 9: Refer to RMT/DIR/0001 Enterprise Risk Management Framework for determining the level of risk.

Shareholder Value-creating Opportunities			Description of Risk	Risk Treatment & Evaluation										
Risk No.	**Objective** *What do I want to achieve? (Set clear objectives)*		**Risk** *What is the risk to the objective? (Cause and Impact)*	**Existing Controls** *What controls do I currently have in place to manage this risk?*	**Current Risk Analysis** *Assess the risk considering Consequence & Likelihood*			**Proposed Controls** *Are further controls required to manage this risk?*	**Accountable Officer** *Who will implement the proposed controls?*	**Due Date** *When are the proposed controls due?*	**Residual Risk Analysis** *Assess the risk considering Consequence & Likelihood*			
					C	L	Level of Risk (Extreme / High / Moderate / Low)				C	L	Level of Risk (Extreme / High / Moderate / Low)	

5. RISK ASSESSMENT APPROVAL

Prepared By:

Chris Langes
Technical Officer
Operations

As the certifying authority having responsibility for the designated work activities and issues identified within the Risk Assessment, I hereby accept and endorse the results of the assessments in so far as they relate to my respective area of accountability and responsibility. I have duly escalated the approval of any treatments not within my authority or delegations.

I hereby agree to undertake those activities and responsibilities that have been designated to me in the above risk assessment.

Note: The safety and business risk assessments above meet the defined requirements in PRI/0014/COR and RMT/DIR/0001 and subsequently contributes to satisfying the related risk management obligations.

Treatment Owner Endorsement: and Approval:

Endorsed by:	Darren Brehmer QLD Field Support Manager Operations	***Endorsed by:***	<Name> <Title> <Business Group>
Endorsed by:	Peter Williams Senior Electrical Engineer Engineering Solutions	***Endorsed by:***	<Name> <Title> <Business Group>
Endorsed by:	<Name> <Title> <Business Group>	***Endorsed by:***	<Name> <Title> <Business Group>
Endorsed by:	<Name> <Title> <Business Group>	***Endorsed by:***	<Name> <Title> <Business Group>
Endorsed by:	<Name> <Title> <Business Group>	***Endorsed by:***	<Name> <Title> <Business Group>

I am satisfied this risk assessment has been conducted in accordance with PRI/0014/COR and Aurizon Enterprise Risk Management Framework RMT/DIR/0001, and that the deliberations and findings reflect the scope and intent of the risk assessment.

Note: This assessment finds that the legal provisions requiring the obligations to ensure workplace health and safety will be met via application of the stated hierarchy of controls and any additional actions, including monitoring as defined in this risk assessment.

Endorsed By:

Simon Lymbery
Vice President Engineering Services

Date:

If safety and/or business risk levels are high or extreme.

Endorsed By:

Lindsay Cooper
A/Executive Vice President Operations

Date:

If safety and/or business risk levels are extreme

Endorsed By:

Board Approval

Title:

Date:

This page is intentionally blank