

RailBAM® - AN ADVANCED BEARING ACOUSTIC MONITOR: INITIAL OPERATIONAL PERFORMANCE RESULTS

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SUMMARY

An advanced bearing acoustic monitoring system for rail rolling stock, RailBAM®, is being used for predictive condition monitoring of bearings across mixed freight and captive fleets. Introduced by Australian Rail Track Corporation following an eight year development, RailBAM® System reports have provided diagnostics information on raceway and looseness/fretting faults across axle box and package bearings. Detectable bearing fault severity levels are reported as Low, Medium or High, these being determined from trials using bearings salted with faults considered condemnable according to standard railway practice, and trended over time. Data automatically flows within minutes from trackside measurement station through algorithms to the RailBAM® Trending Database, resident on the operators' workstation. Faults are routinely trended over many passbys, often for distances of 30,000 kilometres, allowing fault progression to be monitored closely. As levels approach High-level alarm, operators can schedule maintenance in an optimal manner. RailBAM® methods enable direct detection of looseness/fretting mechanisms and have shown that looseness/fretting faults can exist without raceway faults. Operational data shows that the onset of bearing faults from wheel impacts has been predominantly affecting spherical-roller axle box bearings. Looseness/fretting faults are detected clearly across axle boxes and package bearings. While operators use the RailBAM® data in different ways, in all cases operators have experienced strong improvements in their fleet bearing condition and this has been reflected in large reductions in the number of "hot boxes" and derailments experienced across the ARTC and neighbouring networks.

INTRODUCTION

Six RailBAM® Bearing Acoustic Monitor Systems are operational within rail networks in southern Australia. These systems provide automatic measurement and trending of bearing faults across mixed traffic over several networks, across multiple operators and cover approximately 100 train movements per day. The most experienced user is the Australian Rail Track Corporation (ARTC). Following prototype development of the RailBAM® System for condition monitoring of rolling stock bearings by Australian National and Vipac Engineers & Scientists Ltd (VIPAC), initiated in 1993 and completed in 1998, the ARTC sponsored completion of an initial commercial RailBAM® System.

This paper discusses specific operational features of the RailBAM® Systems and provides details of operational results regarding the detection of a wide range of bearing faults, their trending over time through various fault severity levels and system validation of fault detection via bearing inspections.

Traditional technologies employ a "go/no-go" strategy. Hot Box detectors sense an infrared signature that may indicate a bearing is at its imminent failure point. This usually necessitates immediately stopping the train to examine the

bearings on a stationary train, often expensive for the operator while the search for the failing bearing is not always productive. In contrast, VIPAC's RailBAM® is sensitive enough to identify a wide range of bearing faults as they develop, allowing underway trending of a bearing population for 1000's of kilometres before outright failure occurs. Since bearing faults are tracked with vehicle tags, the maintenance department can remove bearings from service in a planned manner.

PRINCIPLE OF OPERATION & SYSTEM DESCRIPTION

Each RailBAM® installation collects bearing fault (and wheel flat) data for each train passing steadily through the system for operational speeds in the range 30km/h to 130km/h and all train lengths, and in both directions. The RailBAM® System processes data from every wheel, on both tracksides.

The RailBAM® System discerns genuine bearing defects from other train noise including flanging, wheel flats, bogie noise, etc. and reliably detects and consistently ranks at least the following bearing faults:

- Cone faults
- Cup faults
- Roller faults
- Looseness/ Fretting

RailBAM® identifies “NOISY” wheel sets (“flanging”), as an indicator of poorly tracking bogies or poor wheel profile that may result from poor bogie alignment. RailBAM® also detects and locates wheel flats that emit acoustic signature within the train consist.

The principal of operation is based on identifiable sound characteristics emitted by bearing and ‘acoustic’ wheel faults. These faults excite structural resonances that carry and radiate a periodic bearing fault signal. Proprietary signal processing techniques allow the bearing fault signal to be extracted from the structural noise, enabling fault identification and classification. An acoustic array gives greatly improved spatial discrimination (“directionality”), while de-cross-talking, using the measured wheel-array geometry and acoustic propagation physics reduces, in software, the influence of a large fault on an adjacent axle. Secondary inputs provided by wheel detectors form an integral part to the signal processing and provide the means of locating faults along the train.

Figure 1 presents a hierarchy of fault types across bearing and wheels that are routinely and reliably detectable and trendable by the RailBAM® System: bearing faults include raceway and roller defects, loose or spun cones, fretting or back face wear while wheel faults include flanging and ‘acoustic’ wheel flats.

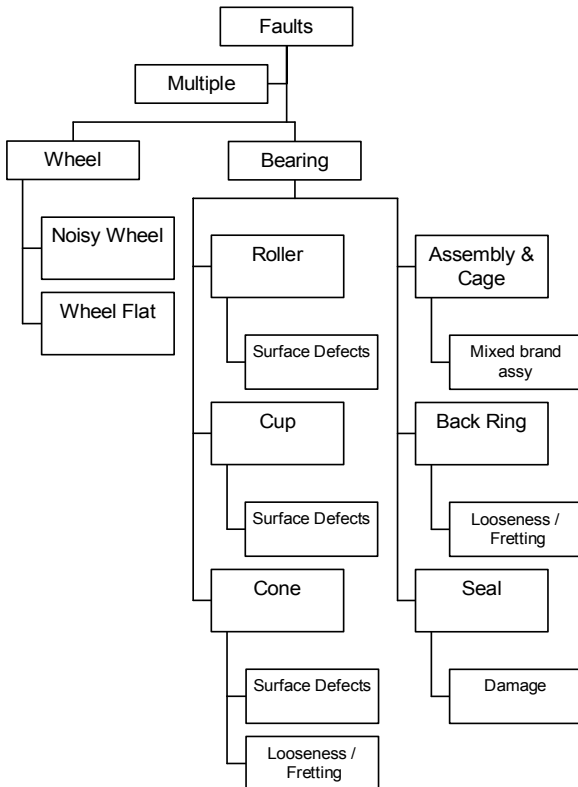


Figure 1: Bearing & Wheel Fault Hierachy – RailBAM® System

The RailBAM® System applies to both Package & Axle Box bearings over wide range of load classes and all major bearing manufacturers. Figure 2 presents photographs of various bearing faults routinely detected, identified and ranked by the RailBAM® System.



Cup and Cone Spalls – Package Bearing (PB)



Cup Fault in Axle Box Roller Faults in PB



Fretting and Back Face Wear



Worn Seals

Figure 2: Range of Bearing Faults that are routinely Detected, Identified and Ranked by the RailBAM® System

Three fault levels have been determined from a series of test trains with known seeded faults and practical usage of the system, giving a reliable process for isolation and trending of severe and developing bearing faults. Bearings with developing faults have been monitored and trended for more than 300,000 kilometres.

The installed ARTC system is shown below in Figure 3.



Figure 3: Photograph of ARTC's RailBAM® Installation at Nectar Brook

Acquisition and analysis of the incoming data are performed by COTS digital acquisition cards, mounted in an industrial-grade high performance computer. Hardware is rack mounted inside the RailBAM® Wayside Enclosure. All system data is stored on hard disc. In the event of power interruption, the computer automatically reboots into a "system ready" status. The RailBAM® System provides "health" parameters for all sensors: wheel detectors and shutter position sensors are continuously checked and microphones are checked after each train pass-by. If problems are identified, appropriate alarms and warnings are generated and highlighted by the Alarm Monitor of the Website.

Results provided by the RailBAM® System include full **Train Management Reports** (all axles) and **Pass By Summary** reports (axles with bearing faults and/or wheel flats only), containing Bearing Faults and Wheel Flat diagnostics by axle and wagon and as available, tag identifiers. Three fault levels are provided for isolation of severe and developing bearing flats, with provision for a greater number of fault levels if required. Parameters for adjustment of these fault levels are available for user tuning and/or investigation and so reflect the operators' experience or maintenance philosophy.

Data from each train is communicated via ISDN line to the customer's RailBAM® Server where they are imported into the RailBAM® Trending Database. (Micro-wave links and Satellite communications systems are also in operation.) Reports of "severe and urgent" faults, e.g. those faults where it could be considered immediate action is required, are provided to train operators immediately via e-mail. Otherwise, reports are made available to train operators via the Trending Database, with an option for third party review.

Trending of identified bearing faults is carried out within the **RailBAM® Bearing Condition Trending Database**, written with a Microsoft Access user interface but using SQL Server to provide higher performance for large installations. This database brings together data for all bearings with faults and allows graphical examination of the history of any and all bearing faults.

Key features of the RailBAM® Trending Database include:

- Automated and Manual Download of measured train data to the Trending Database with capacity for data storage for at least two years' trains
- Trending analysis by an individual and/or class of bearings.
- Trending data for each of the aforementioned faults is available to be viewed by the operators if required. This data includes bearing fault characteristics and rankings.
- Sound files are readily available to enable auralisation of said faults, if desired.
- Data can be grouped according to owner or operator, while data from different operators is secure and available only to the owner/operator, thereby providing commercial confidentiality.
- Data from any individual operator or sub-group of operators is presented in a statistical and graphical format, including
 - "Most Seen, Top NN" bearings, to identify worst offenders where NN can be any number but usually less than 50.
 - Overall Statistics and Monthly Statistics for individual operators and for the overall network usage.
- The Trending Database can be interrogated for any past period for which data exists.
- The Trending Database caters for bearing removal and untagged and 'orphan' cars (where wagon owner to a tagged wagon has not yet been assigned)
- Email Alarms are issued by the Trending Database to advise / alert to bearings whose trend indicates an approach to a risk situation.
- Data export is available.

Processing time for a 200 wagons long train at 50 km/h or more, is less than 10 minutes.

The ARTC system has been located in the field since December 2001, with system availability exceeding 97%.

OVERVIEW OF OPERATIONAL BEARING FAULT DETECTION

Derailments and related incidents are one of the most destructive and expensive disruptions to the train operations, impacting heavily on the rail industry. A study was conducted into the history of rolling stock-initiated derailments, investigating the cause, type, severity and number of incidents on the ARTC Network. By far the most common and severe of incidents were as a direct result of bearing and wheel failures.

Due to the expanse and remoteness of the network, ARTC has concentrated on preventative detection systems such as the RailBAM® system, rather than reactive systems (hot-box detectors). This gives operators maximum time to remove poor condition rolling stock from service before failure, thereby minimising interruption to services.

Since the introduction of the RailBAM® system in December 2001, the operators have actively used the RailBAM® system as a maintenance tool to locate and action bearings with suspected bearing faults.

On the ARTC Network the split between axle box type bearings and package bearings is approximately equal. The predominant sizes of tapered roller package bearings are D and E classes. The predominant sizes of pedestal axle boxes (Spherical Roller Bearings) are the 9R and 18R classes.

Initial validation of the detection of raceway faults (type of fault and severity level) where there was reasonable control of inspections of reported faults showed that the RailBAM® System reliability exceeded 95%.

The reliability of RailBAM® for detection of looseness/fretting faults is also high but is complicated by differing reconditioning standards for fault observation, inspection and classification, as discussed later.

Proprietary methods are being developed to address the difficult issue of detection of loss of lubrication in underway bearings using their acoustic signature.

Detection of faults in locomotive bearings is complicated by the influence of other mechanical noise sources: work over the next year is planned to address this application.

Operator Interaction

The action each operator takes in the removal of known bearing faults can be quite different and depends on the size of their wagon fleet and access to maintenance facilities. After a bearing has been identified with a high level fault, some operators have opted for the approach of immediately removing this bearing on completion of the wagon's journey, while other operators have used the method of trending the bearing defect as it develops over time before taking action.

Since the implementation of the RailBAM® system the number of bearing faults operating over the ARTC network has reduced significantly as operators remove identified bearing faults from service.

Approximately 130,000 bearings are analysed per month by the ARTC RailBAM® Site. Figure 4 demonstrates the diminishing number of faults in operation over time, for both Freight Trains and the Super-Freighter Trains.

The majority of the freight trains (23 Tonne Axle loads and an average speed of 80km/hr) have seen the number of High-level bearing faults in service reduced to half the original number since the introduction of the RailBAM® system.

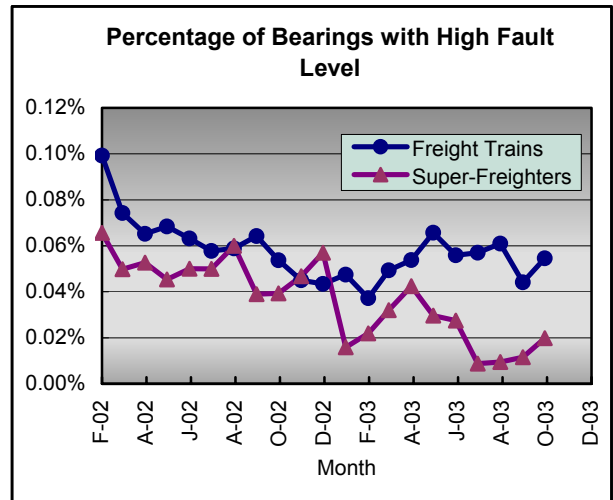


Figure 4: Reduction in High-level bearing faults since implementation.

Super-Freighter trains, having lighter axle loads and running at higher speeds, have managed to reduce the number of High-level faults to one third of the original number. The removal of these High-level faults has also seen corresponding reductions in the number of bearing "hot boxes" and complete bearing failures leading to a reduced number of derailments on the ARTC and neighbouring interstate standard gauge networks.

However diligent the operators are in the removal of bearings identified with faults, there are always "new" High-level faults developing. The development of "new" High-level faults by month is shown in Figure 5.

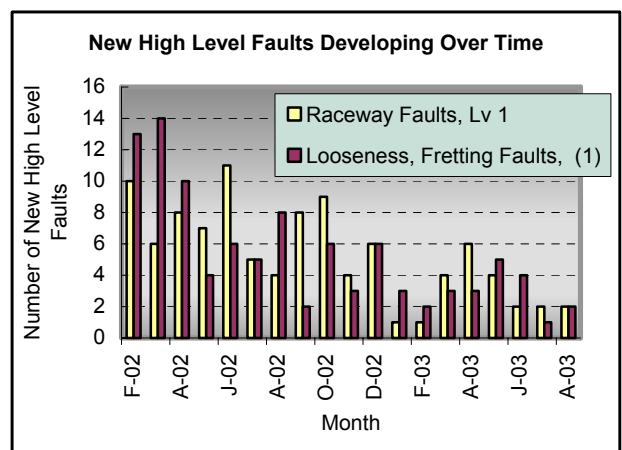


Figure 5: Number of "new" High-level bearing faults developing over time

There is a significant downward trend in the number of new high-level faults developing over time, demonstrating that operators are removing a number of the faulty bearings before they can

develop into significant faults and also improving maintenance practices and conditions leading to the development of new High-level faults.

FINDINGS:

When faults are discovered by the RailBAM® system these are advised as either raceway faults or potential looseness and fretting faults, and then accordingly ranked dependent on the severity of the fault. Physics-based algorithms take into account axle speed, fault type and bearing fault strength.

Looseness/Fretting fault readings are found to be caused primarily by the following faults:

- Loose Bearing Components
- Fretting on the backing ring, seal wear ring or cone face
- Damaged Seals: Caused by impact damage, incorrect installation – (excessive heat has been generated in same cases)
- Loss of interference fit
- Excessive lateral play (Loose Bolts – excessive wear)

In some instances the looseness / fretting reading can be influenced by:

- Rubbing equipment on the axle or wheelset, such as brake rigging, rods, or brake shoes touching the wheel.
- Wheel tread defects (impacts)
- New seals that are “breaking in”.
- Flanging wheelsets

These readings, in most instances, can be segregated from true faults by reviewing the trended bearing history (which may show 'noisy' wheels or wheelflats), closely listening to the sound and conducting examinations of the wagon to eliminate the potential cause of false readings.

Algorithm enhancements to isolate and discriminate against such influences, have been introduced progressively as more is understood about the physical mechanisms as reflected in their acoustic signatures. These algorithms will be developed individually for both axle box and package bearings in the future.

Tapered Roller Package Bearings are predominantly removed due to spalling on raceways or fretting wear on the back face of the cone, the backing ring or seal wear ring.

Axle Box Bearings are predominantly removed due to excessive wear or looseness. Only a small percentage of axle boxes have been identified with raceway faults, which is comparable with the small percentage of spalls on raceways that have been identified when bearings are examined during routine maintenance. Figure 6 shows an example of bearing fault strength data for a stable medium level cup spall fault, indicating the variability that

can exist from measurement to measurement as well as the relatively slow changing characteristics that can occur for some faults. The High, Medium and Low fault levels are shown as horizontal lines, respectively Lvl H, Lvl M and Lvl L. Triangles along the upper Lvl H graph indicate instances of fault detection. The Cup Fault has been observed on 21 pass-bys, equivalent to more than 10,000 kilometers. There is no indication of a Roller Fault in the RailBAM data.

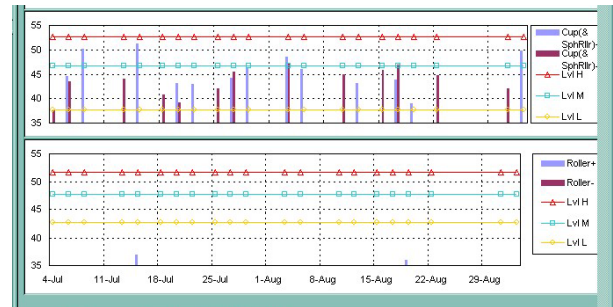


Figure 6: Trend Plots for Cup (and Roller) Fault Indicators, trended over 2 months with 21 observations

The distribution of tapered roller package bearing faults for each operator is quite different: this is partially due to the size and therefore higher loading capacity of the bearing (D or E Class bearings), differing loading configurations, wagon tracking, the route over which the wagon transits and axle length. A representative distribution between two operators is illustrated in Figure 7.

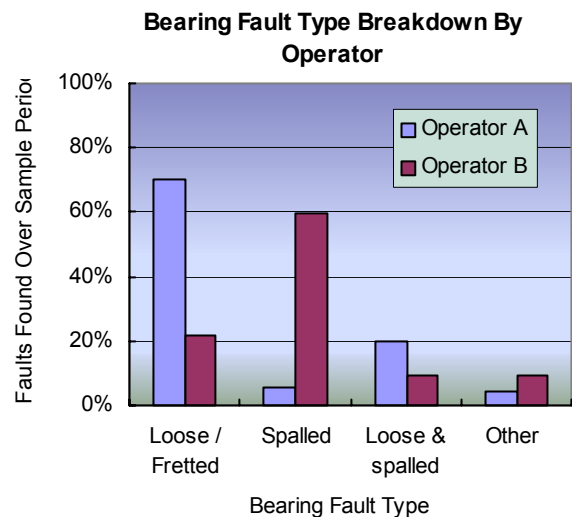


Figure 7: Percentage breakdown of the type of faults found for tapered roller package bearings, by Operator.

When the RailBAM® System has identified fretting and looseness readings in tapered roller package bearings, it is suspected that the primary cause has been due to axle flexure/deflection. This cause appears to be associated with those bearings found on longer axles (in the case of broad gauge bogies converted to standard gauge).

When an axle deflects or bends under the wagon load, the journal's top surface becomes elongated and the bottom of the journal is in compression. During this process the bearing components move axially along the journal and cause circumferential rubbing between the tightly fitted parts: high contact stresses can result, leading to potential surface failure under repeated loading.

Wear on these components aggravates the fretting processes, which becomes more severe and eventually leads to loss of the bearing's clamping force.

A number of bearings have been pulled down for bearing examination following High-level fretting / looseness readings. On examination of the bearing, the examiner has found either excessive or moderate fretting on contact components. In the case of the moderate readings, the level of fretting or back face wear has not exceeded limits as specified in the bearing manuals (AAR condemn limits). Though not exceeding the limits at the time of removal, the fretting had been substantial for the short amount of time the bearing had been in operation, indicating that surface wear is rapid and the bearing is in a fast state of degradation.

There has been much debate about the early removal of these bearings with moderate readings: for example, as the bearing condemn limits had not yet been reached, how much longer they could have stayed in service before removal? However as the severity of the fretting increases, it has been observed that the strength of the fretting signature has a tendency to decrease, introducing the risk that the bearing might later be forgotten due to a more recent but lower severity fault reading.

However, for these cases of High-level looseness/fretting, the rapid rate at which the material had been removed over a short period of time, indicates that the early removal of the bearing may have been the best course of action. Cases of heat discolouration have been found in a few of these bearings with high fretting / looseness readings. In some cases a loss of interference fit and indications of overheating have been evident at the cone/journal interface, suggesting imminent spun-cone conditions. Further studies regarding this problem will be undertaken in the future to assist in maximizing the bearing in-service life without compromising safety.

During the fretting process, debris from the surface becomes dislodged and may circulate in the bearing's grease. In some cases these bearings with moderate to excessive wear have also been found with fragment indentations (minute pitting on the raceways). These indentations eventually propagate into rolling contact fatigue or spalling. These indentations are caused by foreign material passing through the bearing while loaded; this

material is most probably matter from the wear during fretting.

Additionally, there is considerable evidence that looseness/fretting and spun cones can develop prior to any observable raceway faults, for both axle boxes and package bearings. That is, raceway damage is not a pre-condition for development of looseness/fretting.

Many trans-Australian wagons have been identified with raceway spalls developing with vastly varying degradation rates. Some of these bearings have traveled approximately one million kilometers prior to the fault development. In most cases these bearings have been left in service for some time after detection, allowing long term trending history, thereby assisting in the study of long-term fault degradation trends.

The majority of bearings detected with raceway faults, have been examined to find varying types and severity of raceway rolling contact fatigue – ranging from minor brinelling, water etching and spalling. The nature of the rolling contact fatigue is dependent on the method and cause of the defect. Once the surface has become damaged, the ongoing cyclic loading of the bearing on the contact surfaces only assists to increase the damage on the raceway surface. The other roller surfaces eventually become damaged due to debris transfer and the increase in stresses due to the initial damaged surfaces.

Since installation of the RailBAM® System, many cases have been observed of a bearing that has been identified with an initial cup raceway spall and where this spall has eventually caused the development of both roller and cone raceway faults due to ongoing contact between the mating surfaces.

In some cases, this progression has occurred over a return transit trip of approximately 5,000km. Other cases have seen a High-level cup fault operate in a stable manner for over 30,000km before any significant change was observed.

Causal Relationships between Wheel Flats and Bearing Faults

Research has been undertaken in the past year evaluating the relationship between wheel tread defects (wheel impacts) and the development of bearing faults.

To date, the evidence shows that the onset of bearing faults from wheel impacts has been predominantly affecting spherical-roller axle box bearings. Of the past six spherical roller axle box bearings to develop into hotboxes, all cases have shown past evidence of wheel impacts.

Figure 8 shows data for an axle box with a High-level looseness / fretting fault which entered the ARTC network in May. Impact force levels, measured both near the RailBAM site and at other

locations (and therefore on different dates to the RailBAM measurements), range from 200kN to 450kN and are suspected to be due to an out-of-round wheel fault.

The gap in the data between early and late August is as a result of the wagon running on corridors not currently covered by wayside detection systems. The wheel fault was not repaired and so impact force levels remained. Therefore, bearing faults are likely to re-appear in the future.

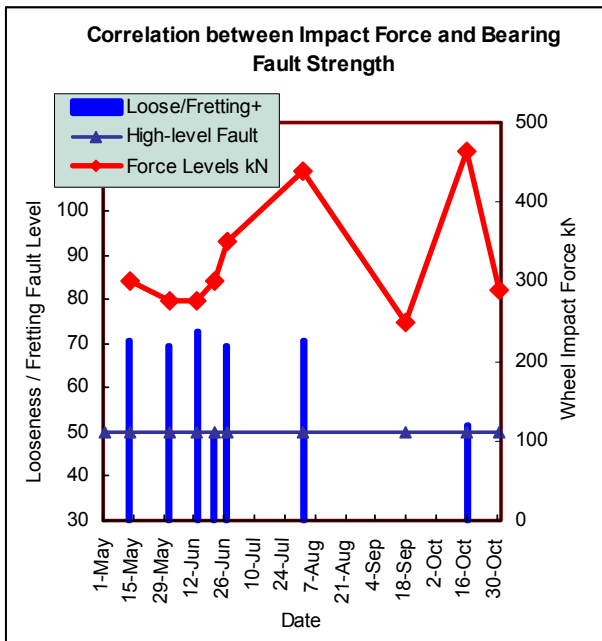


Figure 8: High-Level Looseness / Fretting Fault Strength together with Wheel Impact Force levels.

Some wheel impact history has been short in duration with significant force levels; others have had moderate level wheel impact forces but have been over an extended period of time. The majority of bearings enduring continuous wheel impacts have eventually resulted in significant bearing damage.

After repetitive wheel impact readings, the bearing has been identified as having looseness readings; the bearing has often then developed into a “noisy reading” as the fault reaches significant degradation. Further research will be undertaken in the future to develop algorithms to analyse degradation between impact force readings and the ensuing bearing fault development.

CONCLUSIONS

As every bearing fault is individual and the circumstances as how it came to be in existence differ, it is important to monitor the bearing defect development over time and identify the bearings which are at most risk of failure and remove these bearings as a priority.

The ongoing review of bearing inspection reports obtained from bearings detected by the RailBAM® system, will allow operators and maintainers to obtain an understanding of the development phase of bearing faults. Review of fault development trends for each operator’s rolling stock fleet will lead to improved processes for wheelset maintenance as well as bearing handling practices, which together will lead to ongoing reductions in in-service bearing faults.

BENEFITS

RailBAM® enables, for the first time, train operators to implement Predictive Maintenance of bearings across the rolling-stock fleet.

On the ARTC Network that is monitored by the RailBAM® System,

- The number of axle bearing “hot boxes” has decreased dramatically through the use of the RailBAM® Bearing Condition Monitoring processes. Not only have raceway faults been trended reliably but also bearing faults associated with ‘looseness’ and ‘fretting’ that can lead quickly to “Hot Box” conditions, are directly identified using RailBAM® methods, trended to High Risk Alarm Levels and subsequently removed.
- The number of bearing related derailments decreased by more than 60% as a result of pulling bearings with faults considered severe. Only two bearing related derailments have occurred on monitored track segments for more than 18 months, both of which had prior readings from the system identifying the bearings as containing faults This should be compared with typically five such derailments per annum over the last decade,.
- The RailBAM® Bearing Condition Monitoring process allows the operators to use the trended information as a tool to effectively plan wheel bearing maintenance and improve current processes and standards.