Overview of the Root Cause Investigation into the Failure and Cracking of Underframe Equipment Support Brackets on East Rail Mid-Life Refurbished Trains

Introduction

Trains for railway passenger services are designed and built to industry-accepted international standards. The train-car body housing the passengers is constructed on a very strong underframe, at each end carried by a bogie-set assembly of wheels axles, brakes and other essential items. Below the underframe suspended by brackets is equipment such as electrical power transformers, air compressors for the brake system and other train equipment, and power motor assemblies. Vibration of the underframe caused by track and train-wheel irregularities, which otherwise would cause discomfort to passengers and excessive stress on train equipment, is controlled by a combination of springs and airbags.

During the period 1981-1991, 29 train sets each comprising 12 cars were delivered and brought into service for East Rail. The train cars underwent a train body refurbishment programme during the period 1996-1999. Properly maintained, including mid-life refurbishment, KCRC trains are expected to remain fit for service for up to 30 years.

Another eight East Rail train sets currently in use were supplied by a different manufacturer, and were brought into service from 2002 to provide increased capacity for passenger growth and the extensions to East Rail. The new train sets have shown no evidence of any defects.

The Incident

At about 4.45 p.m. on 21st December 2005, the Platform Supervisor of University Station heard an abnormal sound coming from the underframe of the 3rd car from the front of the southbound train no. M336, a mid-life refurbished (MLR) train set, as the train was pulling out from the station. He immediately activated the Emergency Stop Plunger to stop the train. Concurrently, the train driver in his driving cab noticed a fault light of an auxiliary system was blinking. On the train, an off-duty KCRC staff member also heard the noise and made a report to the driver. The platform supervisor and train driver immediately reported the incident to the Train Control Centre at Fo Tan.

In accordance with standing instructions, to avoid obstructing other services on the track, the driver was instructed to proceed with caution to Platform 4 of Fo Tan Station. There passengers were detrained and within 10 minutes were able to continue their journey on the following southbound train.

It was found on site that a main air compressor unit below the 3rd car from the front was only partially supported with two out of the three mounting brackets detached, resulting in the emission of high pressure air. Following on-site emergency repair, the train set left at 7.45 p.m. for Ho Tung Lau

Maintenance Centre for further inspection.

Throughout this incident, the KCRC staff involved responded promptly in the interests of passenger safety and in ensuring minimal disruption to railway service.

Crack Management

At the maintenance depot, train No. M336 was visually inspected. This confirmed that two out of the three mounting brackets suspending the compressor below the 3rd car from the front of the train had failed, causing flexible pipe-line joints to open and release the high pressure air.

The Crack Management Scheme (CMS) in use at the depot immediately came into effect. The CMS adopted by KCRC is in line with standard practices adopted by railway operators elsewhere. It requires that on finding a significant defect in any part of a train or its equipment, all similar assemblies are inspected until positively cleared by appropriate detailed crack examination methods.

Overnight visual inspection and hammer-tests of all MLR trains produced no evidence of potential compressor mounting bracket failure elsewhere. Further, the fail-safe nature of the train-braking system would have automatically halted the train in the unlikely event of a compressor becoming totally detached. Following trains would also be halted by the automatic train protection signalling system. The overnight inspections enabled authorization of normal train services the following day.

During the 72 hours following the incident, as an immediate interim measure, a temporary secondary strapping was installed to protect against compressor mounting bracket failure on the entire fleet of MLR trains. The material used for the temporary strapping was industrial grade high-strength nylon webbing which could be used in the confined spaces available and for which a certified breaking load was available. A metal cradle was installed as the secondary support to the compressor. The work was completed before the start of train service on 11 January 2006. The use of temporary strapping was later extended to all major items of underframe equipment.

Responding proactively, the depot design and shop floor staff extended the CMS to all underframe equipment. Throughout January 2006, they worked very long hours to design and to install additional support systems at all major bracket locations. During this period 1,465 major items of suspended equipment and about 480 items of non-major items were inspected, with hairline cracks found in the suspension brackets for 189 major items and 46 non-major items. Most of these hairline cracks appeared along the weld lines of the mountings. None of the hairline cracks impacted on the safe operation of the train services.

Given that these hairline cracks were covered in dirt or hidden by protective paint, and located in obscure positions, it was very difficult to discover them by visual inspection. As a result, the inspection process turned to the use of Magnetic Particle Inspection (MPI), a superior method compared with visual inspection or hammer tests. Whilst the latter techniques can locate larger cracks quickly, smaller cracks may be undetected. This accounted for a steady increase in the number of cracks found in the first half of January.

Crack Monitoring

Following the installation of secondary suspension and support frames to all similar items of equipment, agreement was reached with the Hong Kong Inspector of Railways to initiate a crack monitoring programme. The purpose was to evaluate whether the hairline cracks would grow, and if so, how fast. The programme covered 30 major items of underframe equipment, and several rounds of MPI readings were taken by independent specialists.

The crack monitoring programme revealed no significant change in either the number, or size of the cracks already found.

Root Cause Investigation

To assist in the root cause investigation, KCRC engaged international specialist consultants, and a number of independent local professionals and test laboratories. Alstom Hong Kong Ltd, representing the train manufacturer, also made available records pertaining to the original train design and the understanding of the production process, particularly welding and workmanship.

The dominant cause of the cracks found in underframe equipment mounting brackets, with the exception of those involving the air compressors and motor-alternators, is established to be excessive vibration of the car-body. Calculations by the train manufacturer show that the equipment mounting brackets would normally be fit for purpose. However, the excessive vibrations

measured in the MLR trains have increased the fatigue loading on the mounting brackets by up to twice their design limit.

The dominant cause of the cracks in the mounting brackets of air compressors and motor-alternators has been established to be weld imperfections. Moreover, the mounting brackets of air compressors and motor-alternators, in addition to excessive vibration through the train body are subject to further vibration induced by their moving parts.

The source of the excessive vibrations through the car-body is the presence of minute undulations on the rail top on sections of the East Rail track, amounting in total some 36% of the track alignment. When a train is running with a speed of 70 – 90 km/hour over tracks with such patterns, excessive vibration occurs in the car-body and in the underframe equipment mounting brackets. This speed range coincides with the normal speed of East Rail services.

Due to the limitations of the existing technology, it is not practicable to remove the minute undulations along the rail top. The investigation recommended early replacement of those sections of East Rail track in question so as to remove the basic root cause of the excessive vibrations.

As a further precautionary measure the MLR train underframe equipment mounting brackets will be strengthened to withstand the measured level of vibrations and the train suspension system will be enhanced to reduce the transmission of vibrations induced by minute undulations in the rail top.

Work on the measures above is targetted for completion in 2007.

Automatic Train Control

During the period immediately after the incident and the discovery of more hairline cracks, as an interim measure to relieve the stress on the underframe mounting brackets arising from the higher speed of the Automatic Train Operation, the East Rail service was switched to manual Automatic Protection mode. The root cause investigation has found no evidence to show that automatic train control can be considered a direct cause of either the incident or the cracking.

Depot Maintenance Procedures

In February 2006, a leading independent consultant was brought in to review the MLR trains maintenance schedules and provide an opinion on their adequacy and effectiveness. In addition, three other experts were brought in, such that the combined views given were benchmarked against international standards with particular reference to Australia, Germany, North America and the UK.

Prior to the incident that took place on 21st December 2005, KCRC had already commissioned a safety audit by the American Public Transport Association (APTA), which included the KCRC maintenance procedures. APTA found that KCRC regimes are very strong.

The international experts brought in after the incident agreed with the APTA finding. Furthermore, it was concluded that KCRC engineering management and maintenance staff achieved an impressive level of professional performance in relation to the immediate post-incident recovery and risk mitigation programme. The international experts noted the high levels of reliability achieved in train performance.

Although the findings of the investigation and independent reviews by specialist consultants show that the KCRC maintenance standards and procedures have not been a contributory factor in the occurrence of cracks in the underframe equipment mounting brackets, the maintenance procedures for the MLR trains will be further strengthened to support the early detection of mounting bracket cracks. Train-based and track-based instruments will also be installed for continual surveillance of the wheel-rail interaction so that further corrective actions, if needed, can be proactively implemented.

Conclusion

The root cause investigation has identified that the incident on 21st December last year and the subsequent discovery of hairline cracks in the underframe equipment mounting brackets of the MLR trains were due to a combination of factors. At no time was passenger safety at risk during and after the incident. The following recommendations arising from the investigation will be implemented by KCRC -

- the critical sections of rail with minute undulations will be replaced as quickly as practicable;
- the supporting brackets of all underframe equipment will be upgraded to withstand the level of train vibrations found in the investigation;
- the suspension system of the entire fleet of MLR trains will be enhanced to more effectively absorb vertical vibrations;
- procedures to facilitate earlier detection of cracks will be introduced into the maintenance regime; and
- track-based and train-based equipment will be installed to monitor vibrations arising from the interaction of the train wheels with the track.

All of these enhancement measures are targetted for completion in 2007. The findings and the recommendations in the root cause investigation report have been reviewed and endorsed by an Independent Review Panel appointed by KCRC led by Ir. Edmund Leung.

Kowloon-Canton Railway Corporation

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