Condition Based Monitoring in Railway

KH Kim Hung LEE† and Dennis Kong Wan CHAU*

Abstract – This paper presents the railway applications of Condition Based Monitoring (CBM), which have been developed and implemented in the metro system of Hong Kong since 1989. In this paper, the limitations of traditional preventive and reactive maintenance approach in railway operations environment will be explained. CBM has been a proven technology to effectively enhance the RAMS performance of equipment and optimize the maintenance resources, thus reducing the overall life cycle cost. As an example, the technology of Radio Frequency Identification Device (RFID) tag with temperature sensor is used to capture and transmit the main transformer temperature back to maintenance centre via a fixed trackside TCP/IP network. A user-friendly monitoring and analysis software was also developed to provide real-time alarm and trend prediction on transformer temperature. The system is capable of providing early alarm before equipment failure and mitigating incidents which are critical to safety and service performance of the railway.

Keywords: Condition based monitoring, Maintenance, Diagnosis, RFID

1. Introduction

MTR Corporation is responsible for operating and maintaining over 1,900 passenger train cars with every effort placed on pursuing the highest level of safety and reliability. Apart from prudent operation/maintenance procedures, specific tooling was also required to track down premature failure/behaviour in order to prevent them from becoming notable multiple failures at a later stage. This is where we always strive to bring appropriate technology into our scope to push our asset performance to new heights.

Condition Based Maintenance (CBM) was therefore selected as one of the initiatives to be amalgamated into our daily operations. CBM technology has been developed and implemented in the MTR since 1989. Under CBM, measurements such as vibration, oil contamination, temperature, electric current and voltage, etc. are sampled in order to monitor and ascertain whether the equipment, be it mechanical or electrical, is operating normally. The CBM analysis enables proactive maintenance, optimization of maintenance frequency, thus minimizing the overall life cycle cost. The equipment will also have higher reliability and availability, less breakdown cost and capital spare utilization.

In this paper, the limitations of traditional preventive and reactive maintenance approach in railway operations environment will be explained together with some practical examples of CBM applications in Rolling Stock Equipment.

1.1 Examples of CBM Applications in MTR

CBM has been a proven technology to effectively enhance the RAMS performance of equipment and optimize the maintenance resources. Various monitoring and condition based diagnosis technologies are adopted for a large range of Station E&M, Rolling Stock and Infrastructure equipment which are summarized in Table 1 below.

Among all, the Radio Frequency Identification Device (RFID) technology is one new innovative CBM application introduced in Rolling Stock maintenance, being used in remote data monitoring of the thermal performance of train-borne equipment.

2. Radio Frequency Identification Device (RFID)

2.1 Remote data monitoring system

Live operational data is always useful for performance monitoring, evaluation and study in the railway industry to facilitate establishment of an appropriate maintenance regime. Installation of passive data logger onto trains was a conventional method used. Real time performance monitoring may sometimes be required on specific subjects
of interest for case study. Trained personnel equipped with appropriate monitoring tools have to be deployed on a train that runs on normal route in order to carry out the process practically. Non-passenger train is usually required since equipment cubicals may have to be opened or particular doors may need to be locked for signal wiring to run through hence posing inconveniences to passengers. This may therefore affect accuracy of the study value since loading or effects posed by passengers were omitted.

Remote monitoring system is considered to be more viable in obtaining a better result passively. The system will also benefit front-line staff in active monitoring of train healthiness and planning for service adjustment if any irregularity was detected during the service day.

For engineers, it is always beneficial to closely monitor the thermal performance of train-borne equipment to confirm the equipment performance status and send early alert of any premature failure. Temperature reading on the train-borne 25kV electrical transformer is one of the critical parameters that indicates its performance especially when passenger loading varies. An active RFID product transmitting temperature data is identified as the most cost-effective solution in the market. Transformer temperature data can be captured and transmitted to the maintenance centre via trackside RFID receivers to detect overheating or abnormal loading. Transformer temperature can therefore be monitored remotely when necessary.

### Table 1. CBM applications in MTR

<table>
<thead>
<tr>
<th>CBM techniques</th>
<th>Equipment used</th>
<th>Key applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibration Analysis</td>
<td>Transducer, spectrum analyzer</td>
<td>Fan, AHU, Chiller, Escalator, Pump</td>
</tr>
<tr>
<td>Tribology / Oil Analysis</td>
<td>Oil analyzer</td>
<td>Chiller, Escalator, Transformer</td>
</tr>
<tr>
<td>Thermo-analysis</td>
<td>Infra-red images</td>
<td>ACB, Transformer, Switchboard</td>
</tr>
<tr>
<td>Ultrasonic Detection</td>
<td>Ultrasonic Leakage Detector</td>
<td>ACB, Transformer, Switchboard</td>
</tr>
<tr>
<td>Machinery Balancing</td>
<td>Photo cell, laser beam, etc</td>
<td>Fan, AHU, Pump</td>
</tr>
<tr>
<td>Ultrasonic detection</td>
<td>Ultrasonic Testing Vehicle</td>
<td>Rail</td>
</tr>
<tr>
<td>Optical / laser imaging</td>
<td>Track / Overhead Line Geometry Vehicle</td>
<td>Contact wires and rail</td>
</tr>
<tr>
<td>Mechanical measurement</td>
<td>Hand-held for axle crack</td>
<td>Axle</td>
</tr>
</tbody>
</table>

### Table 2. Comparison of active and passive RFID tags

<table>
<thead>
<tr>
<th>Conventional Passive RFID Tags</th>
<th>Latest Active RFID Tags</th>
</tr>
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<tbody>
<tr>
<td>- RFID passive tags are commonly found in applications such as Octopus Cards, it can transmit a unique ID to the reading point for processing.</td>
<td>- Active tags are battery powered and transmit signal autonomously to the server computer</td>
</tr>
<tr>
<td>- Passive tags obtain power from reader using a coiled antenna within tag for energizing the tag’s electronics</td>
<td>- Active tags technology enables the transmission of unique ID as well as other signals measured by the attached sensors (e.g. temperature)</td>
</tr>
<tr>
<td>- Passive tags can only be read at short distances and must be facing the reading directly in order to obtain power.</td>
<td>- Battery powered active tags have longer transmission range of 100 meters</td>
</tr>
<tr>
<td></td>
<td>- Active Tags can be installed at underframe of vehicles where the tag and reader is not in the line of sight</td>
</tr>
<tr>
<td></td>
<td>- Temperature and unique ID is transmitted every 30 seconds</td>
</tr>
</tbody>
</table>

#### 2.2 Selection of Technology

Other than RFID, remote data monitoring systems are available in the market based on different technology such as 3G, WiFi, GPRS, etc. At the initial stage, the merits of all the available technologies have been carefully considered. Due to the safety complexity of railway equipment, the application of any wireless technology is subject to even more constraints and considerations when compared with use in other industrial or domestic environment. These constraints comprise electromagnetic compatibility, wide temperature range, high vibration level, etc. There is no off-the-shelf product in the market which can meet all of these requirements without substantial investment cost.

To seek the best solution, the maintenance and design team identified an active RFID product which can transmit temperature data at short range. A comparison between the use of active and passive RFID tags is given in Table 2.

The product includes an integrated RFID tag and temperature sensor together with a track side receiver which utilizes 2.4GHz ISM frequency for communication. The merit of this product is on the integrated package which provides necessary protection against water penetration, wide temperature range, high vibration and dusty / oily environment in the underframe of passenger trains. The design of external sensor enables temperature measurement of up to 150°C without affecting the tag’s electronics. See Fig. 1 for active tag with sensor.
2.3 Trial implementation

While the first challenge of the harsh railway environment can be solved, the RFID technology still faced other obstacles including the efficiency of data transmission under the metallic structure of train underframe and high electromagnetic interference from electric traction system. These reliability issues cannot be tackled without putting the equipment onto the train for test and trial run. With a series of fine-tuning in RFID tag and receiver position, the system was then put into service trial:

- To identify a position on the main transformer where temperature changes in the transformer can be measured, and where the temperature sensor head and the RFID tag can be suitability installed
- To calibrate the temperature sensor so that the temperature changes in the main transformer can be correctly interpreted
- To select a position at trackside adjacent to Fo Tan Station for the installation of the RFID readers
- To analyse the collected data for its rate of successful data transmission and data healthiness

The trial suggested possible means to tackle these environmental constraints, e.g. special copper adapter was introduced to enhance thermal conductivity between the
2.4 System architecture

A full RFID EMU main transformer temperature monitoring system is finally established consisting of trackside equipment installation and fleet-wide installation of the RFID tags as illustrated in Fig. 3.

From the technical perspective, RFID technology is affixing active RFID tags with temperature sensors to capture and transmit EMU main transformer temperature data back to engineers in the Maintenance Centre via a fixed trackside TCP/IP network. The backbone of the RFID receiving network is installed at the trackside of Fo Tan Station. See Fig. 4.

The final stage of development involves the information technology requirements for presenting measured data from the sensor to engineers in the maintenance centre. Exhaustive research was made to understand the RFID data structure, software development needs and communications requirements. The needs analysis shows a custom made software had to be designed to:

- Collect data from each train automatically and store in a database
- Compare temperature data of the four transformers on each trainset
- Provide warning to engineers in the maintenance centre when any one of the four transformers shows significant temperature variance (cascading failure warning)
- Build-in flexibility to add additional monitoring parameters

RFID data collected by the reader is sent to a PC through TCP/IP packets. The processing PC will decode according to the tag’s data structure. The battery level is also captured within the data structure and when the RFID shows low battery life, the system will alert the maintenance centre to plan for battery replacement.

A dedicated terminal at the depot maintenance centre displays the latest figures immediately and with the assistance of the analysis software, provides real-time alarm and trend prediction on transformer temperature.

Warning message will be triggered when the lowest and highest temperatures of the four transformers in a train differ by 15°C or more and the maintenance centre will be prompted to check for premature failure. The threshold for temperature alarm is adjustable via the setup page of the system.

Fig. 4. RFID Site Installation at Fo Tan Station.

Fig. 5. Customized user-friendly monitoring interface.
2.5 Results

More than 46 cases were detected by the RFID system between June 2010 and Mar 2011 and faulty equipment was concluded in 25 cases. Other cases were resolved by sending technicians onboard to rectify the fault.

This system has proved to be efficient in reducing at least one case of 5-min service delay per year in the East Rail Line due to transformer over-temperature failure.

The system can be adopted to monitor the thermal performance of any train-borne system depending on where RFID sensors are placed. With the same concept, real-time remote monitoring of the axle bearing temperature via RFID active tag was conceived to be effective in flagging up premature axle bearing failure.

3. Conclusion

CBM has been a proven technology to effectively enhance the RAMS performance of equipment and optimize maintenance resources. CBMS technology is widely adopted in MTR and the RFID systems presented in this paper are MTR’s latest innovations which can be further developed for other applications in the railway industry.

Making use of the existing RFID receiver network as a backbone, remote data monitoring can be extended to other EMU equipments such as:

- axle bearing seizure detection
- traction motor temperature monitoring
- brake jam detection

LEE KH Kim Hung Ir K.H. Lee obtained his BEng in Mechanical Engineering and MSc in Building Services from The University of Hong Kong in 1993 and 1996 respectively. He joined MTR Corporation as a graduate engineer in 1993 and has been working for the Corporation for over 17 years of railway experience focusing on all aspects of rolling stock maintenance & operation, He was involved in the opening of Lantau and Airport Railway and was the person in charge of subsequent setup of rolling stock overhaul workshop at Siu Ho Wan Depot. He had also actively participated in overseas growth business for London Overground in 2007 and Melbourne train franchise bidding and post-operation from 2008 to 2010. He is currently at a position of Rolling Stock Asset Development Manager responsible for managing various rolling stock life extension strategies and project implementations.

CHAU Dennis Kong Wan Dennis Chau joined the MTR Corporation in 1998 as a graduate engineer. Since coming to MTR, he has served in the Rolling Stock Maintenance Department for over eight years and opened the train maintenance depot at Tseung Kwan O in 2002. Over the years, he has undertaken maintenance strategy review for a number of train types including CAF trains running on Lantau Airport Railway and Modernized trains running on Urban Lines. In 2008, he also helped accomplish the study on asset life assurance of Modernized trains and confirmed the feasibility to extend its service life from 40 years to 50 years, bringing significant values to the Corporation in terms of asset utilization. Dennis has also extended his knowledge on asset management in overseas franchises of MTR including the Metro Train Melbourne and London Overground. Dennis is now the Maintenance Support Manager in the Corporation.