Tsang, H.L. and Ho, T.K. (2002) ***Application of reliability-centred maintenance technology on electric trains.*** In: Proceedings of the 3rd International Conference on Traffic and Transportation Studies (ICTTS 2002), 23-25 July 2002, Guilin, China.

Application of Reliability-centred Maintenance Technology on Electric Trains

H.L. Tsang[1] and T.K. Ho[2]

Abstract

This paper demonstrates the application of the reliability-centred maintenance (RCM) process to analyse and develop preventive maintenance tasks for electric multiple units (EMU) in the East Rail of the Kowloon-Canton Railway Corporation (KCRC). Two systems, the 25 kV electrical power supply and the air-conditioning system of the EMU, have been chosen for the study. RCM approach on the two systems is delineated step by step in the paper. This study confirms the feasibility and effectiveness of RCM applications on the maintenance of electric trains.

Introduction

The usual practice of preventive maintenance scheduling of EMU in an electrified railway system is to first formulate the maintenance programmes from the manufacturers' recommendations and then carry out appropriate modifications regularly as the operating experience accumulates. As for the safety concerns, systems with safety related functionalities, hidden or otherwise, are identified as safety-critical systems so that special review and control of maintenance activities can be imposed. Inevitably, this methodology cannot completely avoid any hidden risks that have not yet emerged. To provide high quality of service with limited resources, railway operators always seek for a more systematic approach to explore the rooms for improvement on maintenance scheduling of EMU.

Traditional methods for determining preventive maintenance tasks always start with the issue of preserving equipment operability, and such methods tend to focus the entire task selection process on what can be done to the equipment. RCM is a

---

[1] Industrial Training Officer, Vocational Training Council, VTC Tower, 27 Wood Road, Wanchai, Hong Kong; phone: +852 2836 1098; email: hltsang@vtc.edu.hk

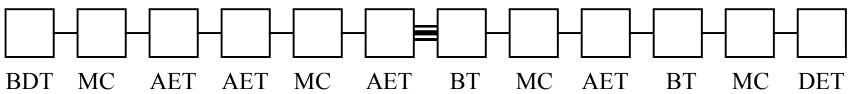
[2] Assistant Professor, Department of Electrical Engineering, Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong; phone: +852 2766 6146; email: eetkho@polyu.edu.hk

process to determine what must be done to ensure that any physical system continues to do whatever its users want it to do in its present operating context [Moubury, 1997], [Smith, 1993]. It is a major departure from the traditional practices because its basic premise is to ‘preserve function’, instead of ‘preserve equipment’.

This paper demonstrates the merits of RCM concept by applying it to analyse and develop the preventive maintenance tasks for the EMU system in the East Rail of KCRC.

EMU of KCRC East-Rail

KCRC has a fleet of thirty 12-car trains, each of which consists of four 3-car EMU running in a 25kV a.c. traction system [GEC, 1996]. The configuration of the 12-car train is as follows:



BDT : Battery Driving Trailer (Cab) MC : Motor Car AET : Auxiliary Equipment Trailer

BT : Battery Trailer DET : Driving Equipment Trailer (Cab)

A single arm pantograph mounted on the roof of each motor car collects the traction current from a 25kV overhead wire. Current from the pantograph passes to the main transformer to provide the necessary voltages for the traction drives, motor alternator and auxiliary circuits. Thyristor-controlled devices and pneumatic brake devices are employed to control the traction and braking of the train respectively.

RCM Application on Preventive Maintenance Programme

Functions and Boundaries of Systems

With respect to the prime function of transporting passengers safely, efficiently and comfortably, an EMU can be split into 13 systems. Each system performs a series of key functions that are required of an EMU. With the same principle, each system can be decomposed into several subsystems/equipment and each of them performs at least one significant function as a stand-alone item. To provide a base for system selection and a starting point of RCM analysis, function-oriented worksheets, which specify in detail the functions down to subsystem/equipment level, are worked out for the whole EMU. The primary, secondary and protective functions covering the operational, safety and efficiency aspects have all been considered.

Systems Selection

In this study, two systems: the 25kV electrical power system and the air-conditioning system are chosen.

System Description and Functional Block Diagram

25kV Electrical Power System

The main function of the 25kV electrical power system is to collect 25kV a.c. electrical power from overhead wire and step it down to a suitable voltage level for traction system and auxiliary electrical system. The current will then return to the rails through the earth return brushes.

The system consists of 9 subsystems: pantograph, lightning arrestor, vacuum circuit breaker, earth switch, high tension cable, main transformer, earth return, auxiliary compressor and automatic power control. The system functional block diagram of the 25kV electrical power system is depicted in Figure 1.

Air-conditioning System

The function of the air-conditioning system is to provide air-conditioning and ventilation to saloon and driving cab for the comfort of passengers and driver.

All cars are fitted with two roof-mounted air conditioning units. Each unit comprises compressor, condenser and fan, evaporator and fan associated with drive motors, filters, receivers and coils. The compressor and condenser fan motors are supplied by the three-phase output of the motor-alternator (MA) set, while the evaporator fan is supplied from the 110V d.c. supply. The saloon air-conditioning units of the whole train are controlled in driving cab through saloon air-conditioning control train wires.

System Functional Failures

To ascertain the actions to prevent, mitigate, or detect onset of function loss, how functions might be defeated should be firstly determined. As RCM analysis focuses on loss of function, the failure statements should be addressed to functions, not the equipment. To facilitate functional failure analysis, 'Equipment - Functional Failure'

Matrices are worked out. The matrices relate functional failures to the equipment since it is the functional failure that efforts should be put into preventive maintenance to avoid such occurrence. The matrix for the pantograph is illustrated in Figure 2.

Failure Mode and Effects Analysis (FMEA)

For each component listed in the equipment-functional failure matrices, the exact way a component may fail to produce the specified functional failure in question is identified. Each equipment failure may have one or more causes of failure. For example, a pantograph head failure may be resulted from carbon strip broken because of regular knocks by external objects or existing internal cracks. For the failure mode of broken carbon strip of pantograph head, the three levels of failure consequence are: unable to contact overhead line properly at local level; loss of 25kV electrical power at system level, and loss of traction & auxiliaries at plant level.

By going through the FMEA process, the columns for failure mode/cause of failure, and failure effect and consequence are identified for each subsystem of the 25kV electrical power and air-conditioning systems.

Failure Consequence Evaluation

The purpose of this step is to further prioritise the emphasis and resources that should be devoted to each failure mode, recognising that all functions, functional failures and, hence, failure modes are not created equal. The consequences of each failure mode are evaluated by asking the following logic questions.

- Will the loss of function caused by the failure mode on its own become evident?
- Does the failure mode cause any safety consequence?
- Does the failure mode cause any environmental consequence?
- Does the failure mode have a direct adverse effect on operational capability?

This process is a qualitative process known as the logic tree or decision tree analysis (LTA). By going through the logic tree analysis process, the consequence evaluation for each cause of failure of the 25kV electrical power and air-condition systems are compiled.

Task Selection Process

To select the most effective preventive maintenance tasks, another set of logic questions should be raised.

- Can ‘On Condition Task’ reduce the failure rate?
- Can ‘Scheduled Restoration Task’ reduce the failure rate?
- Can ‘Scheduled Discard Task’ reduce the failure rate?
- For failure mode affecting safety or environment, is a combination of tasks technically feasible and worth doing?
- For hidden failure, is a failure-finding task technically feasible and worth doing?
- For hidden failure, could the multiple failures affect safety or environment?

By the first three logic questions for task selection and the experience on EMU maintenance, whether a ‘Time Directed (TD)’ task or ‘Condition Directed (CD)’ task is effective can be identified.

The fourth and fifth logic questions for task consideration are specifically designed for hidden failure consequences, deciding whether a scheduled failure-finding task is effective to prevent the occurrence of the failure mode and; more importantly, whether the multiple failure could affect safety or environment. If the failure mode on a component could cause a multiple failures which would lead to safety or environmental hazards and there is no effective preventive maintenance task to avoid the failure mode, the component/equipment must be redesigned. The last logic question is to ensure that any failure mode with safety and environmental consequence has been tackled.

Task Content and Interval

While the most effective types of actions have been identified, the task content and task interval for each failure mode should be defined to prevent, mitigate or detect onset of function loss.

Operational check is always the most effective and efficient way to ensure the functions and performance of an equipment and system. However, operational check in some cases is not feasible and cannot always cover all the actual conditions. In such cases, inspection of signs of wear and tear, current conduction, commutation of motors, etc. should be adopted as on-condition tasks. For on-condition tasks and scheduled restoration tasks, reliability data and failure history of equipment should be referred for the determination of task intervals.

Results

Lists of 52 recommended preventive maintenance tasks and 5 recommended redesign items for the two systems have been developed. A comparison between the RCM recommended maintenance tasks with the existing routine maintenance practice is tabulated in Figure 3.

Of the 40 recommended preventive maintenance items in the 25 kV electrical power system, 8 items are new tasks and 32 items are existing tasks in balanced examinations including 11 items with RCM recommendation of changing maintenance interval. On the other hand, 10 existing maintenance items in the system are recommended to withdraw by RCM. For the air-conditioning system, only 2 of the 12 recommended tasks are new and 3 items are recommended by RCM to alter the maintenance interval. There is only 1 existing maintenance item which RCM recommends to delete. The greater proportion of differences between the tasks defined by traditional approach and the RCM approach in the 25 kV electrical power system is due to the fact that the failure consequences of the system have greater safety and operational impacts where RCM focuses on.

The study also suggests 5 redesign items, of which 4 are proposed in the 25 kV electrical power system to enhance the safety, reliability and maintainability of the system and the EMU plant. The remaining one is to improve the response to any air-conditioning fault with an aim to maintain a reasonable level of comfort for passengers. Proposal of redesign items is a breakthrough of RCM approach in deriving maintenance activities from the traditional approach as such activities are always constrained by the existing design.

Conclusions

The study has brought a number of benefits to the maintenance of EMU. Firstly, as the failure consequence on safety, environmental and operational aspects have been deliberated in RCM analysis, the objective of enhancing the safety, reliability, availability and maintainability of EMU can be realised by adopting the RCM recommended tasks. Secondly, a staggering 10.6% reduction on the existing manpower for the maintenance of two major subsystems of EMU can be achieved by adopting the RCM recommended preventive tasks. Despite the fact that EMU consists of numerous subsystems, this reduction on manpower and the task selection process reflect, to certain extent, that the cost effectiveness of maintenance programmes can be maximised by implementing the RCM recommended tasks. In addition, the performance level of EMU can be upgraded.

The study confirms the feasibility and effectiveness of RCM applications on the first line maintenance of EMU; and it induces further applications on other maintenance activities in railway systems.

Acknowledgements

The authors are grateful for the kind permission from KCRC on the use of their technical information and the presentation of results in this paper.

References

KCRC EMU Maintenance Manual (1996) GEC Alsthom.

Moubray, J. (1997). *Reliability-centred Maintenance*, Butterworth-Heinemann Ltd.

Smith, A.M. (1993). *Reliability-centred Maintenance*, McGraw-Hill, Inc.

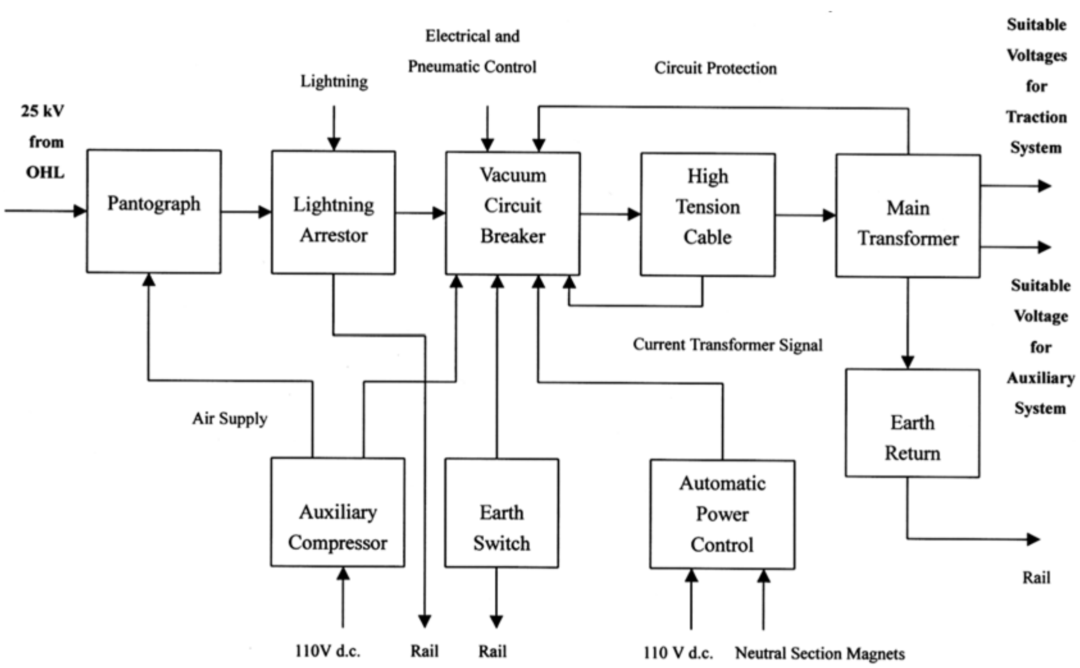


Fig.1 Functional diagram of 25kV power system

Equipment-Functional Failure Matrix
Pantograph (25kV Electrical Power System)

Equipment-Functional Failure Matrix	101A01 Fails to contact overhead line (OHL)	101A02 Fails to provide good current conduction	101C01 Incorrect contact pressure	101C02 Pantograpgh Head bouncing	101F01 Cause damage to OHL supply	101F02 Fails to indicate OHL off position	101J01 Fails to lower pantograph	101K01 Bad contact with OHL	101K02 No quick separation from OHL	101K03 25kV flashover to earth
Panhead	X	X		X	X	X		X		
Braids & Connectors		X								
Raising Cylinder	X		X	X			X	X		
Damper			X	X				X		
Quick Exhaust Valve	X		X					X	X	
Springs	X		X					X		
Frame & Linkage	X									
Pantograph Mounting Insulators										X
Pneumatic Control Equipment	X		X					X		
Electrical Control Equipment	X						X			
Air Feed Insulator										X

Fig.2 Equipment functional failure matrix for the pantograph

Subsystem / Equipment	Existing Balanced Examination Tasks				RCM Recommended Maintenance Tsaks			
	No. of Maintenance Items	Required Man-hours per Unit per Year	No. of Items which RCM Recommended to Delete	No. of Items RCM Recommended to Change Maintenance Interval	No. of RCM Recommended Tsks	Estimated Man-hours per Unit per Year	No. of New Items	Potential Saving per Unit per Year
Pantograph	13	9.21	3	2	11	8.01	1	**1.2**
Lightning Arrestor / HT Cable / Earth Return Brush	5	3.25	0	3	8	3	3	**0.25**
VCB / Earth Switch	6	4.94	2	1	5	6.67	1	**-1.73**
Main Transformer	10	3.97	3	3	8	2.83	1	**1.14**
Auxiliary Compressor	5	1.69	2	2	5	0.8	2	**0.89**
Automatic Power Control	3	2.25	0	0	3	2.25	0	**0**
Total:	42	25.31	10	11	40	23.56	8	**1.75**
Air-conditioning Control	1	0.3	0	1	2	0.2	1	**0.1**
Saloon air-conditioning	8	15.5	0	2	9	14.95	1	**0.55**
Cab Air-conditioning	2	2.85	1	0	1	0.6	0	**2.25**
Total:	11	18.65	1	3	12	15.75	2	**2.9**

Fig.3 Comparison of RCM recommended maintenance tasks with existing routine examination tasks