Mechanics Transport Communications

Academic journal

issn 1312-3823

issue 1, 2010

article № 0464

http://www.mtc-aj.com

RCM METHOD UTILIZATION FOR TRAMCAR MAINTENANCE

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Key words: *reliability centred maintenance, tramcar bogie, scheduled maintenance, initial maintenance programme*

Summary: *This paper presents the maintenance system design of a tramcar in order to ensure safe and effective operation. RCM method (reliability centred maintenance) is used for preventive maintenance programme development. RCM techniques are applied to the bogie of tramcar type T3. On the basis of RCM analysis including significant items categorization according to failure effects, determination of maintenance tasks and assessment of scheduled maintenance intervals the initial maintenance program for the tramcar bogie is created.*

Introduction

Tramcar system creates the essential part of public transport system in many large cities. It is necessary to provide scheduled maintenance of tramcars in order to ensure safe, available and effective operation. For maintenance programme design is possible to use the RCM method (reliability centred maintenance) which is suitable in the cases when object failures can cause serious effects for safety, environment or operation of the system.

The initial maintenance programme for the bogie of tramcar type T3 is created in the paper. The tramcars type T3 and their variations (producer: former ČKD Tatra Prague, Czechoslovakia) are still in operation in many European cities. Their two-axle traction bogie is compounded of two half-frames and suspended bolster. Wheelsets with rubber suspended wheels are embedded in gearbox tube part. Transmission of driving force to the wheelset is made by cardan shaft. The bogie is equipped with three types of brake system, i.e. electrodynamic brake, friction brake and electromagnetic rail brake. The Figure No. 1 shows the design drawing of mentioned bogie.

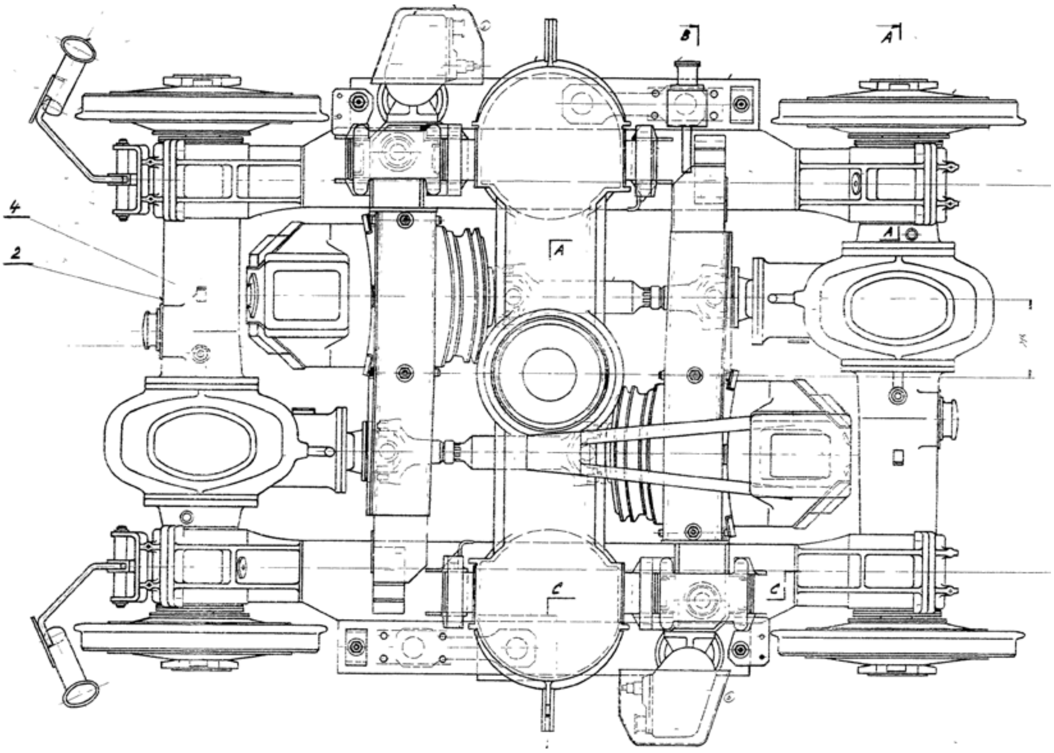

Figure No. 1. Bogie of tramcar type T3, design drawing

Initial maintenance programme design using RCM techniques

Reliability centred maintenance (RCM) is described in the standard IEC 60300-3-11 [1] as a method for establishing a preventive maintenance programme which efficiently and effectively allows the achievement of the required safety and availability levels of equipment and structures, which is intended to result in improved overall safety, availability and economy of operation.

Initial maintenance programme is created in the cooperation of vehicle producer and vehicle operator before setting in operation, or the programme is initiated for existing vehicles due to current maintenance programme improvement. Subsequently the on-going (dynamic) maintenance programme is initiated by vehicle operator and it results from actual maintenance, operational and failure data, new technologies, materials, maintenance techniques and tools.

In maintenance programme design it is necessary to determine vehicle parts intended for maintenance, specify the objectives achieved by maintenance and define maintenance tasks and intervals of preventive maintenance.

Vehicle decomposition and maintenance objectives determination

Objective of decomposition is identification of system functions and physical boundaries on the level of system, subsystems and components. Functionally significant items (FSI) and other nonsignificant items of system are defined in this phase. According to [2], FSI represents system part or component whose failure:

- can influence safety, environment – SSI,
- can have significant influence to operation and maintenance – MSI,
- can have significant economic influence – ESI.

Structurally significant items (SSI) are system parts intended for interception of gravitational, operational, pressure, aerodynamic or control stress and their failure, evident or hidden, can influence safety-critical structure or environment. SSI maintenance objective is depended on object character: safe-life item maintenance will prevent the failure, acceptable damage item maintenance will detect potential failures.

Failure of maintenance significant item (MSI) unfavourably influences vehicle operation and maintenance. Due to this failure it is necessary to implement operational limitations or the vehicle crew has to use extraordinary actions. MSI failure can cause travelling time extension or impossibility of vehicle travel. Restoration of MSI has unfavourable influence to vehicle availability. MSI maintenance objective is limitation of failure probability to acceptable level.

Failures of economic significant item (ESI) do not limit vehicle operation, but failure effects cause increased costs of additional maintenance. ESI maintenance objective results from comparison of yields and costs: scheduled maintenance will have lower costs than elimination of failure effects.

Technical and design documentation for the tramcar bogie decomposition is used. In the first decomposition level the physical boundaries of vehicle single parts are determined, i.e. maintenance of these objects can be based on exchange system principle. Subsequent decomposition levels are required for more complicated vehicle structures, up to structure component level. See the example of two levels decomposition in the Table No. 1.

Functionally significant item (FSI) classification of tramcar bogie components is made according to defined maintenance objectives for SSI, MSI and ESI. See the examples in Table No. 2 – 4.

Table No. 1: Example of bogie decomposition on first and second level

Tramcar type T3	Unit: **Bogie**
No.	**Part, functional system**
10	Side frame
20	Motor transom
30	Wheelset with gearbox
40	Suspended bolster
50	Cardan shaft
60	Traction motor
70	Shoe brake
80	Electromagnetic rail brake
90	Sandblaster
100	Mudguard
110	Flange lubrication system

Tramcar type T3	Part: **Wheelset with gearbox**
No.	**Component**
1	Wheel tyre
2	Wheel disc
3	Rubber suspension element
4	Grounding jumper
5	Axle
6	Axle bearing
7	Gearbox
8	Gearbox tube part

Table No. 2: SSI classification – wheel tyre

Component		**Function**
Wheel tyre		Wheel tyre transmits vertical and lateral forces between rail and wheel disc under the condition of circularity (adhesive rolling of wheelset).
RCM analysis		**Reasons**
SSI	yes	Slewing, displacement, disruption and wheel tyre profile wear result in danger of derailing.
MSI		
ESI		

Table No. 3: MSI classification – rotor winding

Component		Function
Rotor winding		Together with stator winding generate magnetic flux, which creates turning moment of traction motor.
RCM analysis		**Reasons**
SSI	**no**	Perforation of winding insulation acts as hidden failure, when current goes through vehicle frame (safety hazard). Main contactor with maximum relay avoids this failure.
MSI	**yes**	Failure of rotor winding causes malfunction of traction motor. Driver has to use extraordinary procedures.
ESI		

Table No. 4: ESI classification – lubricating wick

Component		Function
Lubricating wick		Lubrication wick adjoins to flange and performs its lubrication. That decelerates wear rate of flange.
RCM analysis		**Reasons**
SSI	**no**	Function failure does not cause safety hazard.
MSI	**no**	Function failure does not cause tramcar malfunction.
ESI	**yes**	Failure (absence of lubrication wick) causes insufficient lubrication of flange, thereby faster wear rate. It causes increasing of wheel tyre maintenance costs.

Assessment of maintenance tasks and maintenance content

Determination of applicable and efficient preventive maintenance tasks for functionally significant items (FSI) is going from approach using decision logic tree analysis. This analysis uses a group of sequential YES/NO questions, answers determinate analysis trend and define maintenance tasks which can avoid the failure or can reduce failure effects. There exist next types of maintenance tasks [1]:

- lubrication or servicing,
- operational or visual check,
- inspection, functional check or diagnostics,
- restoration,
- discard and replacement.

For structurally significant items (SSI) it is necessary to ask questions for all types of maintenance tasks. If it is not possible to find any applicable maintenance task, not even their combination, then it is necessary to transform structure design of this item due to safety.

For MSI it is obligatory to ask questions for first three maintenance task, for ESI is obligatory to ask questions for first two maintenance tasks. If it is not possible to find any applicable maintenance task, not event their combination, then it is possible to transform structure design of this item or apply corrective (after-failure) maintenance system.

In decision making of maintenance tasks it is necessary to specify damage sources causing object degradation, i.e. accident damage (AD), environmental damage (ED) and fatigue damage (FD).

Specification of maintenance tasks for tramcar bogie is made for all FSI on base of mentioned decision logic tree analysis. Example of analysis results for wheel tyre is given in Table No. 5.

Table No. 5: Example of maintenance means determination – SSI

Tramcar type T3		Component **Wheel tyre**	Damage sources AD/FD, acceptable damage
Maintenance tasks – SSI		Task details for **Yes**, reasons if **No**	
Lubrication or servicing	Will the task reduce the rate of functional deterioration? YES / NO	**YES** Flange lubrication by lubricating wick.	
Operational or visual check	Will the task detect the functional degradation? YES / NO	**YES** Slewing, displacement, surface cracks (visual check). Flat places of wheel tyre profile (hearing check).	
Inspection, functional check or diagnostics	Will the task detect the functional degradation? YES / NO	**YES** Crack check (defectoscopy). Measurement of wheel tyre profile, eccentricity of gauge circle	
Restoration	Will the task reduce the failure rate? YES / NO	**YES** Turning of wheel tyre profile on wheel lathe.	
Discard and replacement	Will the task prevent the failure? YES / NO	**YES** At moment of deep crack occurrence, achievement of minimum wheel diameter.	
Applicable task combination	Is it possible to use the combination of tasks? YES / NO		
Structure change necessary!		**Objective: Maintenance shall prevent first failure occurrence.**	

Content of maintenance programme contains two groups of maintenance tasks: group of preventive maintenance task and group of non-scheduled maintenance tasks.

Objective of preventive maintenance tasks is identification of degradation and prevention of reliability and safety reduction under their inherent level, i.e. such level that is possible to achieve, if maintenance is provided efficiently.

Objective of non-scheduled maintenance tasks is maintenance or restoration of object into working order in which can perform required functions. These tasks result from preventive maintenance tasks and from reports on incorrect operations or information on warnings of imminent failures.

Determination of maintenance intervals

Both aspect of vehicle safety and aspect of preventive maintenance costs are necessary to consider, while determination of scheduled maintenance tasks. It is suitable to use data from vehicle operation for mathematical modelling of efficient maintenance intervals. In case, when suitable data are not available or there are not any experiences with similar vehicle parts operation, the maintenance intervals can be set by expert workers on the basis of their experience and opinion.

It is necessary to create a reliability model of vehicle for maintenance intervals calculation. For statistical model of distance between failures distribution of vehicle components the Weibull distribution is suitable due to its variability. Two parameters Weibull probability density function *f(l)* is given [3]:

$$f(l) = \frac{\beta}{\eta} \cdot \left(\frac{l}{\eta}\right)^{\beta - 1} \cdot e^{-\left(\frac{l}{\eta}\right)^{\beta}} \tag{1}$$

where: β is shape parameter of Weibull distribution [-],
η is scale parameter of Weibull distribution [km],
l is random quantity – distance between failures [km].

SSI maintenance intervals are calculated as a defined low percentile of distances between failures ensuring high level of component reliability, e.g. for wheels with Weibull distribution parameters $\beta = 2,07$ and $\eta = 133\,726$ *km* the is 10th percentile $l_{0,1} = 45\,060$ *km*.

MSI and ESI maintenance intervals are determined with use of restoration density *h(l)* given by equation [3]:

$$h(l) = \sum_{n=1}^{\infty} f_n(l) \tag{2}$$

where: $f_n(l)$ is probability density function of *n*-th restoration.

Figure No. 2 shows numeric calculation of restoration density of traction motor (with estimated Weibull parameters of reliability) for various scheduled restoration intervals.

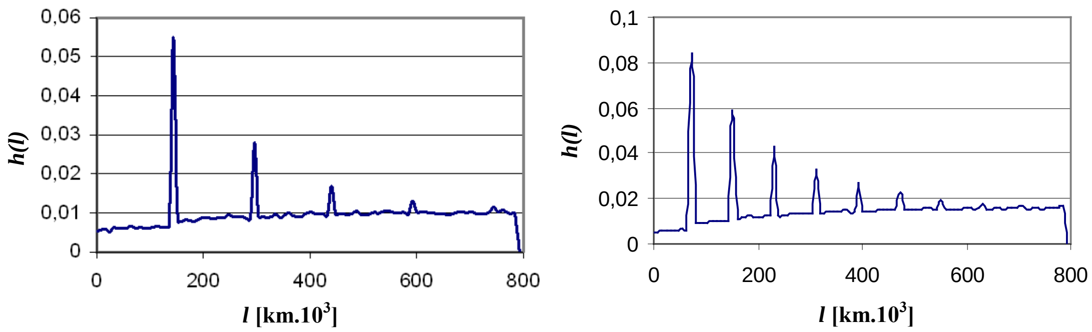

Figure No. 2: Restoration density – traction motor, scheduled restoration 80 000 km, 150 000 km

Number of component restorations is analyzed on the base of restoration density with respect to maintenance interval influence on vehicle availability and maintenance costs, see the example for traction motor (Table No. 6).

Table No. 6: Number of restoration for 1 000 000 km distance, MSI (traction motor)

Unit: **Traction motor**			Weibull distribution parameters	
			β = 1,0747	η =158953 km
Scheduled maintenance interval →	80 000 km	150 000 km	240 000 km	After failure
Scheduled restorations	17	8,5	4,5	0
Unscheduled restorations	6	6	7	9,5
Total restorations	23	14,5	11,5	9,5

It is necessary to include in maintenance programme also intervals of scheduled functional checks given by legal enactments. In the Czech Republic the Decree of Ministry of Transport No. 173/1995 Coll. [4] laying down the operation order of rail companies is obligatory for rail vehicles. At most in two year interval a technical condition check of tramcar has to be performed according to the decree, including vehicle part functional check and brake check for all braking processes.

Initial maintenance programme

Initial maintenance programme using RCM techniques is created for tramcar bogie. It contains list of scheduled maintenance tasks and maintenance intervals (distance or time) for each component classified as FSI. Scheduled maintenance tasks in maintenance programme should be grouped into zone maintenance to reduce vehicle maintenance downtime.

Example of initial maintenance programme for a tramcar bogie part (wheelset with gearbox) is shown in Table No. 7.

Table No. 7: Initial maintenance programme, wheelset with gearbox

Tramcar type T3	Unit: **Wheelset with gearbox**		No. 30	
Component	**RCM cat.**	**Maintenance task description**	**Interval**	
			km	**time**
Wheel tyre	SSI acceptable damage	Flat places (hearing check) Visually: slewing, displacement, surface cracks Inspection: wheel profile, eccentricity of gauge circle, defectoscopy: crack check	- 5 000 50 000	daily - 2 years
Wheel disc	SSI acceptable damage	Visually: displacement on axle, surface cracks, nut tightening Defectoscopy: crack check	5 000 50 000	- -
Rubber suspension element	SSI acceptable damage	Inspection: dimension check, rubber hardness measurement or diagnostics	50 000	-
Grounding jumper	MSI	Visually: condition check Inspection: resistance measurement	5 000 150 000	- -
Axle	SSI acceptable damage	Visually: check a connection of pressed disc Inspection: measurement of wheelset gauge, defectoscopy: crack check	5 000 50 000	- 2 years
Axle bearing	MSI	Check of bearing heating (touch), clack (hearing check) Inspection: measurement of bearing clearance or diagnostics	- 150 000	daily -
Gearbox	SSI acceptable damage	Gear-wheels running (hearing check) Visually: tightness check, oil leakage Inspection: gearing condition check, oil quantity and quality, defectoscopy	- 5 000 50 000	daily - -
Gearbox tube part	SSI acceptable damage	Visually: tightness check, surface cracks Defectoscopy: crack check, oil quantity and quality	5 000 50 000	- -
Summary list of maintenance tasks				

Conclusion

Tramcars of type T3 still make numerous group of vehicles ensuring public transport in large cities. A lot of these vehicles have been modernized, especially their electrical package, interior etc., but using original vehicle bogies, supposing their several years operation. Therefore implementation of maintenance system using RCM techniques is suitable for tramcar bogie due to increase of vehicle overall safety and operation efficiency through continually developing operational maintenance programme.

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