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ON THE DEPENDABILITY OF RECONDITIONED ROLLING STOCK

The article suggests formulas for identification of the mean failure rate of reconditioned rolling stock. The authors present the results of the research of the dependence of failure rate on the scope of lifespan recovery, number and frequency of maintenance operations before rolling stock replacement.

Keywords: *failure rate, lifespan, scope of recovery, maintenance, replacement, frequency.*

1. State of the art

Over the course of rolling stock (RS) operation, current maintenance and overhauls are performed in order to ensure its dependability. It is well known that RS maintenance usually recovers only a part of the original dependability properties.

RS operation inevitably involves failures that are caused by various reasons and can be classified by difficulty to eliminate. The choice of the place and method of failure elimination is very important from technical and economic points of view. Accordingly, all failures should be divided into two groups: performance failure and life-limit failure. The elimination of the first type of failure does not require labor intensive operations and RS operational condition is recovered by replacing, fixing or adjustment of faulty components within the scope of maintenance or current repairs. The remaining lifetime does not change. The advantage of this method is that it ensures complete utilization of the lifetime of almost all RS elements.

The life-limit failure shall be understood as an event that indicates either the complete failure of RS as a whole or components failures that justify a certain lifespan recovery of the whole RS. The elimination of such failures requires labor intensive dismantlement, repair, assembly, adjustment, testing and other activities. This method of failure elimination is more complex and requires a special manufacturing environment. The advantage of this method consists in the recovery of the prescribed lifespan and, therefore, improvement of RS dependability. Life-limit failures are eliminated by means of overhauls (OH) or unscheduled replacements. In the first case a partial, while in the second case a complete RS lifespan recovery takes place.

All maintenance and repair actions during RS operation can be classified by three indicators: the moment of activities: scheduled or unscheduled; type of activities: preventive or emergency; scope of lifespan recovery: no recovery (maintenance or current repairs), partial recovery (overhaul) and complete recovery (replacement).

Over the course of operation due to aging and wear processes the degradation failure rate of RS increases. The dependability theory uses distributions with increasing intensity function to describe degradation failures, e.g. Weibull distribution with the shape parameter above one. Preventive repairs eliminate the increase of failure rate ensuring the required RS dependability level. Therefore, in order to evaluate the dependability of reconditioned RS the most demonstrative indicator, the failure rate, should be used.

The purpose of this article is to suggest formulas for finding mean failure rate that take into consideration the scope of reconditioned RS lifespan recovery, as well as to explore the dependence of failure rate on the scope of lifespan recovery, number and frequency of repairs before rolling stock replacement.

2. Taking the scope of lifespan recovery into consideration

In order to take the scope of lifespan recovery into consideration for the purpose of RS preventive and emergency repairs it is suggested to use as per [1] parameter a as "age" of RS after overhaul. The changes in the life-limit failures due to overhauls and RS replacement is given in fig. 1, where T_{pr}, T_{ir} and T_r are respectively the prerepair, interrepair and total resource of RS. Complete recovery shall mean a recovery that somewhat brings RS to the condition it displayed at the beginning of operation (see point 0 in fig. 1), when the life-limit failure rate equals to zero. That is equivalent to a preventive replacement. In case of repair it is suggested to evaluate parameter a as $a = T_{pr} - T_{ir}$ (see fig. 1). Subsequently, while developing mathematical models of preventive repairs optimization for the purpose of evaluating the scope of lifespan recovery it is suggested to use the non-dimensional parameter $\alpha = a/T_{pr}$. If $\alpha = 0$, that means that RS has been replaced. In case of an overhaul after time τ the «age» of RS reduces from τ to $\alpha\tau$.

3. Failure rate of reconditioned RS

As the distribution of time to degradation failure does not comply with the exponential law, it appears justified to use mean failure rate (FR) for a specified time period, e.g. interrepair period or period to replacement. If we assume that the mean FR is practically constant, we can use the hypothesis of the exponential distribution of time to failure of reconditioned technology.

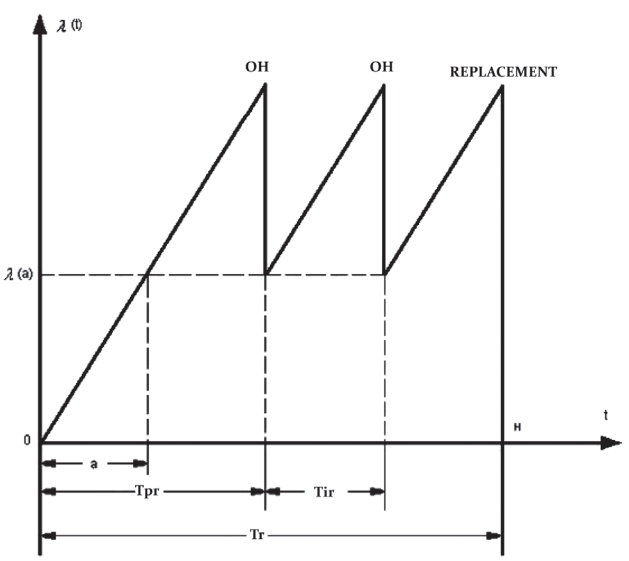

Fig. 1. Change of life-limit failure rate due to overhauls

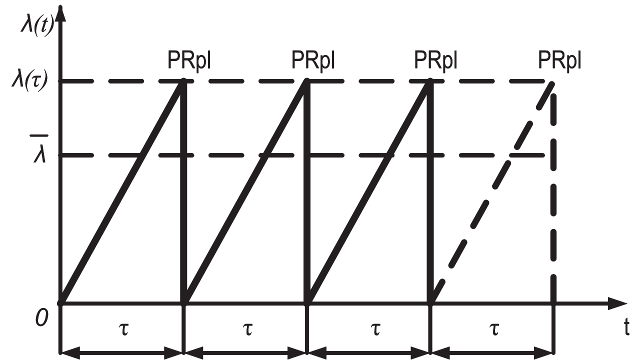

Fig. 2. Change of failure rate due to replacements

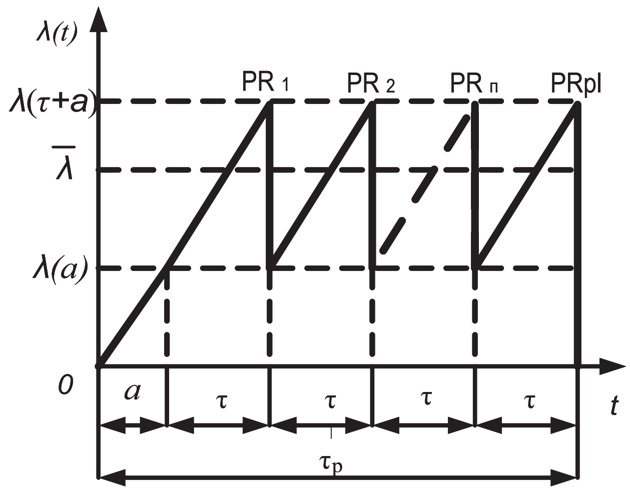

Fig. 3. Change of failure rate due to maintenance and replacements

In [2] the author describes the case of perfect repairs that completely recover the original dependability which is only possible if a device is replaced with a new one. In case of preventive replacement (PRpl) with frequency τ the failure rate λ*(t)* associated with wear and aging goes down to zero (see fig. 2.). With that changes the failure rate distribution, as the curve of FR dependence on the time of operation is replaced with the saw-tooth curve ranging from zero to λ(τ), then back to zero. The mean failure rate $\bar{\lambda}$ (see the dotted line in Fig. 2) in case of PRpl is defined using formula [2]

$$\bar{\lambda} = \tau^{-1}\int_0^{\tau} \lambda(t)\,dt = -\ln P(\tau)\tau^{-1}, \qquad (1)$$

where $P(\tau)$ is the probability of fault-free operation with the time to failure of τ .

In practice, devices are repaired, but not replaced. In that case dependability does not recover completely. In order to take the scope of lifespan recovery into consideration it is suggested to use parameter $a>0$ that indicates the "age" of RS after repair [1]. The value of parameter a is defined on the scope of the activities related to replacement and repair of RS components during repair operations.

In general, in order to recover lifespan after n preventive repairs (PR), RS is replaced. Failure rate evolution is shown in fig. 3. After PR with frequency τ the FR goes down to $\lambda(a)$, while after PRpl with frequency τ_r it goes down to zero. FR at the moment of PR and PRpl is $\lambda(\tau+a)$. Thus, the failure rate curve is replaced with the saw-tooth curve with the range from $\lambda(a)$ to $\lambda(\tau+a)$and then to $\lambda(a)$ in case of PR and from $\lambda(\tau+a)$ to zero in case of PRpl. As PR frequency goes down, the peaks of the saw-tooth curve of the FR function approximate the straight line $\lambda(a)$.

The mean failure rate $\bar{\lambda}$ marked in fig. 3 with a dotted line within interval $0 - \tau_r$ is defined using the formula

$$\lambda = \tau_\rho^{-1} \int_0^{\tau_\rho} \lambda(t)\,dt \qquad (2)$$

where

$$\int_0^{\tau_\rho} \lambda(t)dt = \int_0^a \lambda(t)dt + (n+1)\int_a^{\tau+a} \lambda(t)dt =$$
$$= n \ln P(a) - (n+1) \ln P(\tau + a);$$

Inserting value $\int_0^{\tau_\rho} \lambda(t)\,dt$ in formula (2) and taking into consideration that

$\tau_\rho = a + (n+1)\tau$ (see Fig. 3) we get

$$\bar{\lambda} = \left[n \ln P(a) - (n+1) \ln P(\tau + a)\right] / \left[a + (n+1)\tau\right]. \qquad (3)$$

Let us consider two special cases:

For $n = 0$, when only replacements are made and $a = 0$, from (3) we deduct equation (1);

if $n \to \infty$ when only repairs are made after evaluation of indeterminate forms we get $\bar{\lambda} = \left[\ln P(a) - \ln P(\tau + a)\right]\tau^{-1}$.

Let us consider a case when RS failures are described with a Weibull distribution. Then formula (3) takes the form

$$\bar{\lambda} = [(n+1)((\tau+a)\,k_b/T)^b - n(ak_b/T)^b]\,[a + (n+1)\,\tau]^{-1}, \qquad (4)$$

where T is the time to failure;

b is the parameter of the Weibull distribution shape;

$K_b = G(1+1/b)$, G being the gamma function.

Formula (4) was used in the research of the dependence of the mean failure rate on the quantity and frequency of PR, scope of lifespan recovery and parameter of Weibull distribution shape. Below are given examples of calculation results with representation of parameters T, τ and $\bar{\lambda}$ in non-dimensional form.

It was established that as the number of PR goes down before RS replacement value $\bar{\lambda}$ drops. For example, in case of Weibull distribution if b=4 , T=1000 ,a=50 and $\tau = 200$ we have: for $n \to \infty - \bar{\lambda} = 0{,}131 \times 10^{-4}$; for $n=3 - \lambda = 0{,}124 \times 10^{-4}$; for $n=0 - \bar{\lambda} = 0{,}054 \times 10^{-4}$.

As PR goes down value $\bar{\lambda}$ drops. For example, in case of Weibull distribution if b=4, T=1000, a=50, n=3, we have: for $\tau = 200 - \bar{\lambda} = 0{,}124 \times 10^{-4}$, while for $\tau = 100 - \lambda = 0{,}030 \times 10^{-4}$ 1/hour.

As parameter a goes down (scope of lifespan recovery increases), value $\bar{\lambda}$ drops, while for a= 0 value $\bar{\lambda}$ is defined only by PRpl frequency. For instance, in case of Weibull distribution for b=2, T=1000, τ=200, n=3 we have: for $a=100 - \bar{\lambda} = 0{,}288 \times 10^{-3}$, while for $a=50 - \bar{\lambda} = 0{,}224 \times 10^{-3}$.

Thus, by reducing the frequency or number of PR before RS replacement or increasing the scope of lifespan recovery (by extending the list of activities related to replacement or recovery of RS components during PR) practically any target values of mean failure rate of rolling stock can be ensured.

With the reduction of the coefficient of variation V (rise of parameter b) value $\bar{\lambda}$ drops. For example, in case of Weibull distribution if T=1000, a=50, τ=200 hours, n=1 we have: if $b=2 - \bar{\lambda} = 0{,}214 \times 10^{-3}$, while if $b=4 - \bar{\lambda} = 0{,}117 \times 10^{-3}$. That means that for RS clear signs of aging and wear preventive repairs become more efficient.

Conclusions

1. In order to identify the mean degradation failure rate associated with wear and aging it is suggested to use the formulas given above that take into consideration the scope of lifespan recovery as the result of rolling stock repair.

2. Research shows that for rolling stock that more clearly displays aging and wear preventive repairs are of higher relevance.

3. The mean failure rate value declines, as with the reduction of frequency and number of repairs to rolling stock replacement, and increases with the reduction of the scope of lifespan recovery.

4. By adjusting the scope of lifespan recovery or frequency and number of preventive repairs within the service life, the target value of rolling stock mean failure rate can be ensured.

References

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