RELIABILITY OF DC RAIL ENGINES: ANALYSIS AND PROGNOSIS

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1. Introduction

This article is about the reliability of DC rail engines. Damage of engines is a very important problem in the utilization of electric locomotives. Consequently it is desirable to know the effectiveness of various types of rail engines. Reliability is a measure of effectiveness. Reliability is calculated on the basis of experimental data about the most common defects. It would be desirable to know this parameter in the future. The analysis and prognosis of the reliability of DC rail engines is determined.

2. Analysis

A rail engine is a renovated object (after damage is repaired and it is functional again) and can be represented by a serial structure. Effective utilization of an engine requires proper functioning of every part. A classification of damages (according to serial structure) on the basis of information collected during seven years of use within the locomotive depot Krakow—Prokocim is shown in Figure 1. In these mathematical models all damages are independent.

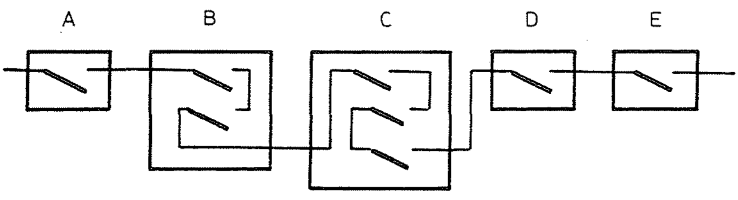

Fig. 1. The classification of damages

A–stator	A1–resistance of insulation
B–rotor	B1–resistance of insulation
	B2–defected shrouding
C–commutator	C1–too great voltage
	C2–singed commutator
D–rolling bearing	
E–little gear	

The time period of efficient utilization of rail engines is a random variable. The relationship between time and reliability is determined empirically using certain assumptions.

The assumptions are:

— the mean functioning time of the traction engine is longer than the repair time,

— a rail engine is a complicated object and repair does not change its reliability in any important way,

— each sample is representative. A single realization does not influence sample properties.

For these reasons repair time of rail engines is omitted. The number of damages was registered in quartile periods of a year. Three types of rail engines were examined:

engine EE 541 — locomotive EU 06/07, ET 22, ET 41,

engine Lk 635 — locomotive ET 21,

engine Lk 450 — locomotive EN 57,

Data are presented in Figure 2.

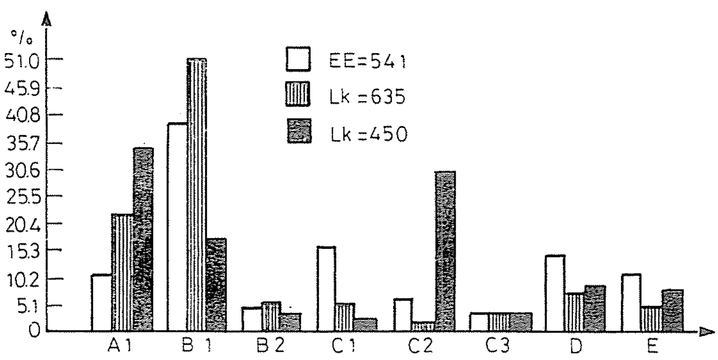

Fig. 2. The damages of rail engines

The reliability (punctual and partition) is calculated by well-known formulas from [1], [2] and [6].

$$R(t_m) = \exp\,[-\,\Lambda(t_m)]$$

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$$\bar{R}(t_m) = \exp\,[-\,\Lambda(t_m)]$$

The mean value of functional engines is determined:

$$N = \frac{\sum_{i=1}^{m} n_i \cdot \Delta t_i}{I_m}$$

where:

n_i = number of functional engines during period Δt_i,
T_m = entire period of observation.

For engines EE 541: $T_m = 25$ $N = 165$,

for engines Lk 635: $T_m = 28$ $N = 393$,

for engines Lk 450: $T_m = 28$ $N = 316$.

Mean value of damages per quartile:

$$m = \frac{M}{T_m}$$

for engines EE 541 $m = 21.44$,

for engines Lk 635 $m = 13.14$,

for engines Lk 450 $m = 9.32$.

Reliability functions for these kinds of engines are presented in Figure 3.

Analysis of reliability functions of these rail engines shows that optimum utilization is not attained. A comparison among damaged parts of engines is shown below:

Damaged part	EE 541	Lk 635	Lk 450	Rail engines in the DDR
Stator	10.5%	27.2%	33.3%	15.9%
Bearings	14.0%	6.5%	7.7%	0.8%
Commutator	23.5%	7.3%	33.3%	40.6%
Rotor	41.4%	55.2%	21.1%	18.6%
Brushholder	no data available			24.1%

Damages to bearings in the DDR are much less than in Poland. Damages to other parts are comparable. Damages are caused by constructional and technological errors made during production of component parts and their assembly. These damages are caused by inadequate (everyday and periodic) technical examinations of rail engines in locomotive depots, incompetent servicing and unsuitable working conditions.

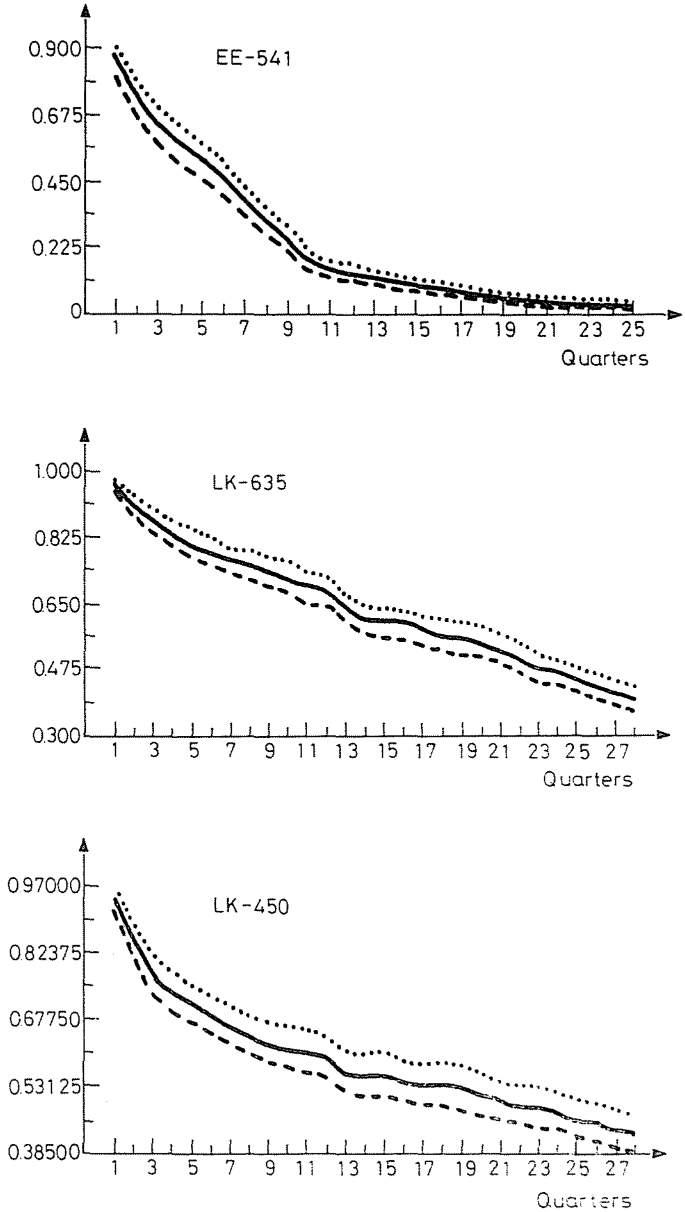

Fig. 3. **The reliability functions of rail engines**

3. Prognosis

Rail engines are used for many years and this is the reason why prognosis of their reliability is interesting. Prognosis was developed in two steps. At first graphical analysis was made. It suggested an exponential function as a good approximation of reliability trends. The next step was to find a mathematical model by statistic–econometric methods and to test it. The model is proposed below.

$$y = a_0 \cdot a_1^x \cdot e^\varepsilon \tag{1}$$

where:

a_0, a_1, ε-parameters,

y — endogenous variable,
x — exogenous variable.

The above exponential model is changed into a linear model by introduction of new parameters:

$$\begin{aligned} z &= \ln y \\ b_0 &= \ln a_0 \\ b_1 &= \ln a_1 \end{aligned} \tag{2}$$

and by logarithmizing equation (1) and it looks thus:

$$z = b_0 + b_1 \cdot x + \varepsilon. \tag{3}$$

The linear dependence (3) between variables (2) is tested by calculating the correlation coefficient:

$$r(x, z) = \frac{\operatorname{cov}(x, z)}{S(x) \cdot S(z)}$$

where:

$$\operatorname{cov}(x, z) = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x}) \cdot (z_i - \bar{z}) \tag{4}$$

$$S(x) = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2}$$

$$S(z) = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (z_i - \bar{z})^2}$$

x_i — a value of variable x
z_i — a value of variable z,
$\bar{x}$ — mean value of x,
$\bar{z}$ — mean value of z,
$S(x)$ — variance of x,
$S(z)$ — variance of z,
$\operatorname{cov}(x, z)$ — covariance of x, z,
$r(x, z)$ — correlation coefficient.

Some r values are shown below:

Correlation coefficient	EE 541	Lk 635	Lk 450
$r(x, z)$	—0.9922	—0.9964	—0.9714

The calculated coefficients manifest a good linear relationship between the variables (3). The structure parameters of models are estimated. Such models are:

Model	EE 541	Lk 635	Lk 450
$z = b_0 + b_1 \cdot x + \varepsilon$	$-0.079-0.1396x+\varepsilon$	$-0.0428-0.0296x+\varepsilon$	$-0.2063-0.0233x+\varepsilon$

To prove correct model application the following stochastic parameters are calculated: coefficient of convergence φ^2, coefficient of determination R^2, and coefficient of multiple correlation R.

Coefficient	EE 541	Lk 635	Lk 450
φ^2	0.0026	0.0047	0.1192
R^2	0.9976	0.9953	0.8808
R	0.9987	0.9976	0.9385

The values of these coefficients testify the correctness of the assumed models. The errors of calculated structure parameters were calculated:

Error	EE 541	Lk 635	Lk 450
$D(b_0)$	0.0078	0.0022	0.0126
$D(b_1)$	0.0005	0.0001	0.0008
$S(\varepsilon)$	0.0189	0.0058	0.0325

Finally the trend functions are:

Engine	Trend function
EE 541	$z = -0.0790 - 0.1396x + \varepsilon$ (0.0078) (0.0005) (0.0189)
Lk 635	$z = -0.0428 - 0.0296x + \varepsilon$ (0.0022) (0.0001) (0.0058)
Lk 450	$z = -0.2063 - 0.0233x + \varepsilon$ (0.0126) (0.0008) (0.0325)

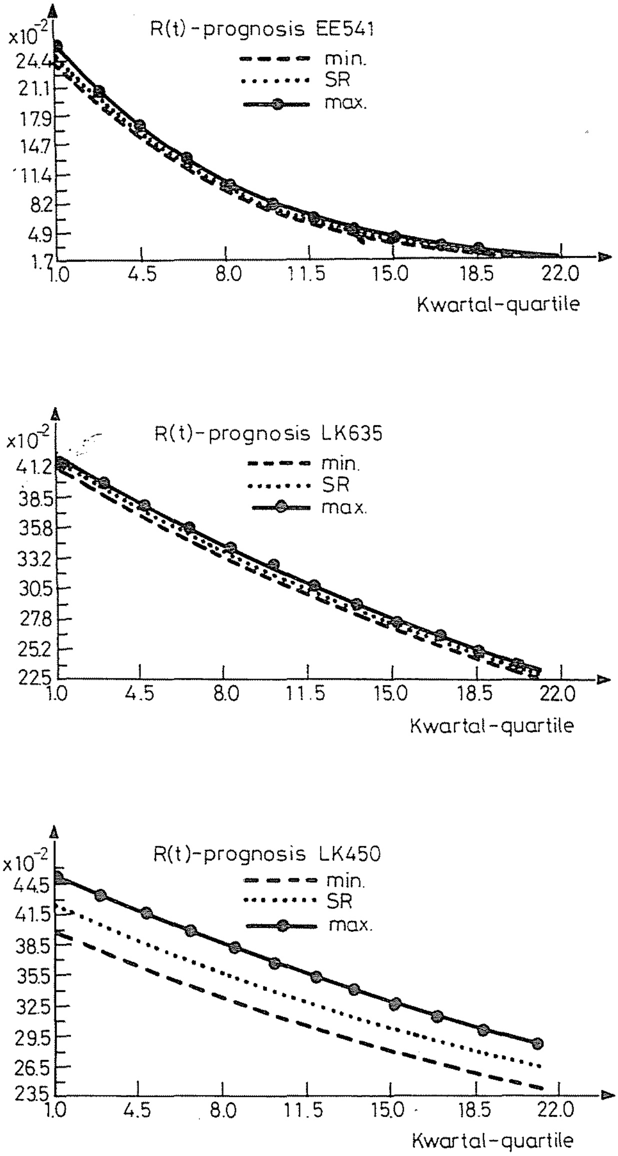

Fig. 4. The prognoses of reliability functions of rail engines

Prognosis of these trends were made. The reverse conversion $y = e^z$ is calculated and the values of the dependent variable y are known. These values are shown in Figure 4.

4. Conclusion

The prognosis enables us to anticipate the necessary quantity of reserve engines in the locomotive depot. Prognoses like this can be made for any locomotive depot.

Ways of improvement of a rail engine reliability can be analysed on three levels:

— production of engines,

— engine servicing,

— a locomotive depot as a direct user of these engines.

Improvement of engine construction and increase in durability of parts are the responsibilities of the producer.

Engine servicing requires special diagnostic equipment. It should enable us to find defects, repare them, and to test the repaired engine.

In the locomotive depot it is necessary:

— to make diagnoses of engines during period review. It renders a proper estimate of their technical state possible and allows us to repair defects.

— to conduct special maintenance during winter. Inadequate protection against snow getting into engines induces dampness of insulation. It is necessary to stuff up intake holes of engines.

Conditions of use have a great influence on the life of a traction engine. Bad rail conditions (on tracks and turnouts), unplanned stops and starts, and riding heavy goods trains up and down cause an increase of engine troubles. It is very important in a mountainous country (like the South of Poland).

Increasing the life-time and durability of rail engines (especially in view of a shortage of reserve engines) is a very important issue. The solution of this problem requires cooperation of locomotive depots, engine servicers and engine producers.

Prognoses like these enable the necessary number of reserve engines in a locomotive depot to be anticipated.

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