NON-DESTRUCTIVE CONTROL: ANALYSIS OF ROLLING STOCK RELIABILITY

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ABSTRACT

In the article the authors evaluate critically the existing calculation method of reliability and durability of rolling stock's component parts basing on the results of non-destructive control and propose corrections which can make it more effective. Probability of failures at different running time, their empirical correlations were determined taking into account the distribution function. Results of testing of wheel set axles reliability calculations are given at the example of locomotives VL80 using the described technique. For calculations the authors used data obtained during maintenance of electric locomotives at locomotive depots of Privolzhskaya railway in 2010-2011. The calculations show that the running time to failure of wheel set axles obeys an exponential distribution law, the failure rate is constant, which means that the deterioration of their technical condition with increasing operating time of up to 4.5 million km does not occur, and failures are of random (sudden) character.

ENGLISH SUMMARY

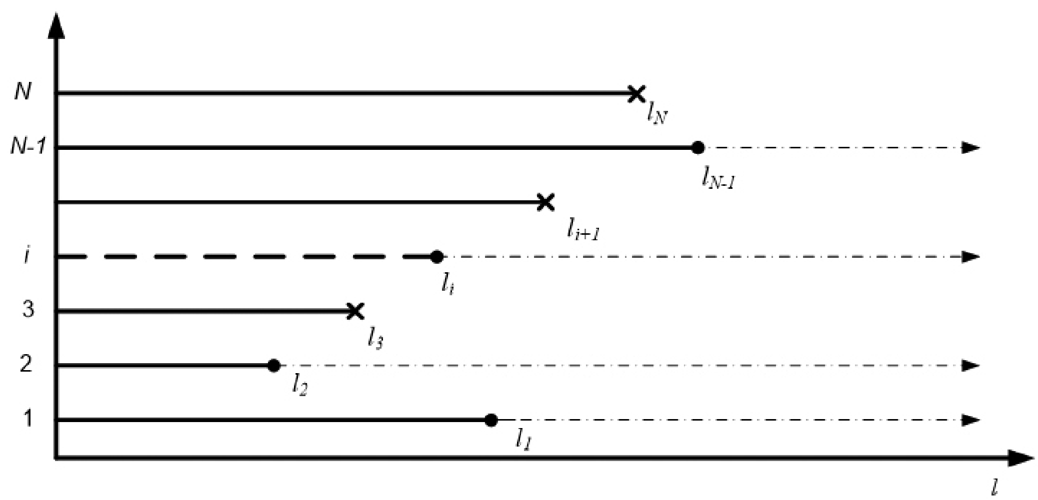
Background. *At the present stage of railway transport development, with increasing speeds, growth of intensity of transportation and weight of trains, the crucial task of ensuring safety is solved via the introduction of a new type of traction rolling stock (hereinafter-TRS). Increase in operational reliability, which is achieved through the necessary safety margin, is laid at the design stage, as well as is ensured by schedule preventative system of maintenance and repair implemented by JSC «Russian Railways», providing the application of methods of nondestructive control (hereinafter- NC) of main units and parts in technological processes. The formation and growth of defects during the operation threaten trouble-free operation of the rolling stock. Ensuring of traffic safety through the timely detection of fatigue and factory operational defects in the critical elements of the rolling stock brings a huge economic impact. The solution to this problem is achieved by modern physical methods of NC.*

One of the most common NC methods in maintenance of traction rolling stock is an ultrasonic method. This method is based on the emission and the subsequent analysis of the parameters of high-frequency elastic mechanical oscillations (ultrasound waves) passed through a controlled product. Ultrasonic method is used to control elements of the wheel set: axle, spider centre, rim, large gear. During manufacture, operation, maintenance and repair of railway rolling stock technological process provides a considerable amount of NC control tests of component parts and assemblies. The analysis shows that its results are usually limited to the assessment of defect ratio (probability of failure) of a specific part, due to one reason or another.

Objective. *The objective of the authors is to calculate the parameters of reliability and optimal timing of repair based on the results of diagnostic of units and component parts of the rolling stock with the use of various types of non-destructive control.*

Methods. *The authors use analytical method, engineering methods, and method of non-destructive control.*

Results. *Any set of inspected component parts (sample) before or while repair of the rolling stock usually has different running time from the date of manufacture. Therefore, according to the information on the results of NC of a part it is impossible to determine the dependence of probability of failure on its running time. In this case, the defect ratio (probabil-*



Pic. 1. Information on the running time of the sample of N component parts in the process of non-destructive control:
• – functioning component part; × – nonfunctioning component part (failure).

ity of failure) is the average point estimate, which does not allow us to predict the technical condition of a component part. If we know running time of each inspected component part out of a sample N from the moment of its production, the information on the running time of all N component parts in the process of monitoring over time can be presented graphically (Pic. 1).

If the running time to the moment of control of N component parts are presented as an ordered series (Pic. 2), the resulting information will assess point estimate of failure probability Q^* [1] for a particular value of running time.

The failure probability $Q^*(l_i)$ at running time l_i of i inspected component parts, k of which proved to be defective, will be:

$$Q^*(l_i)=\sum_{i=1}^{k}\frac{1}{N(l_i)}, \qquad (1)$$

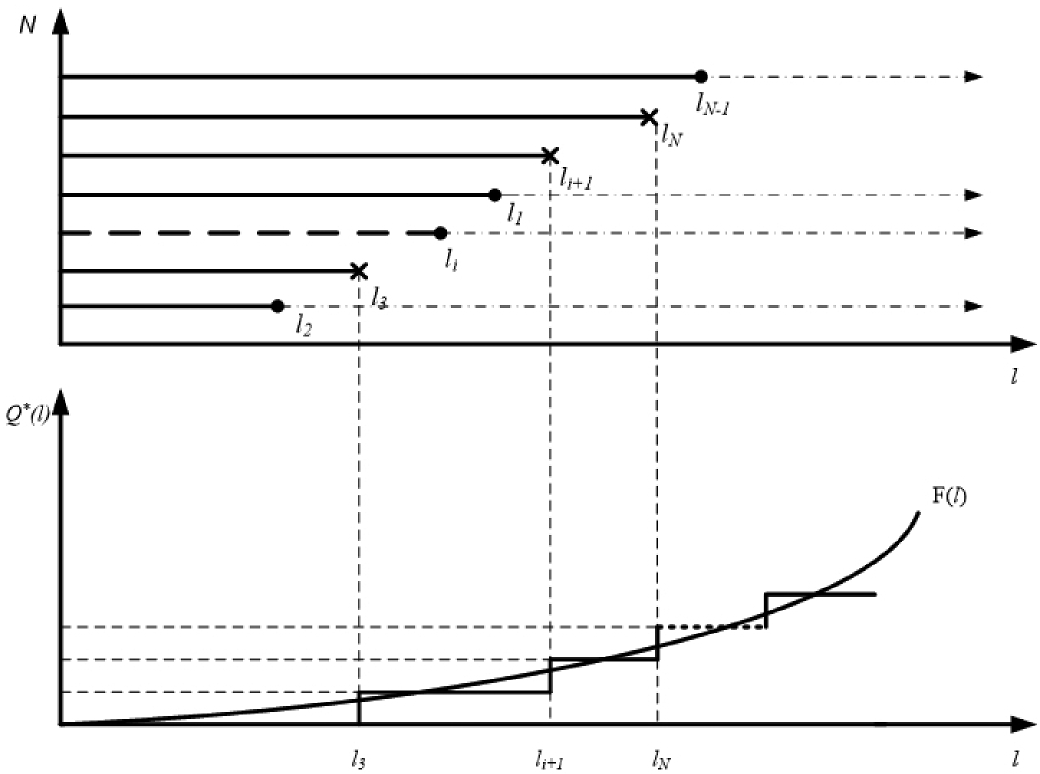
where i is a serial number (in the ordered series) of a failed component part;

l_i is running time to failure of a component part;

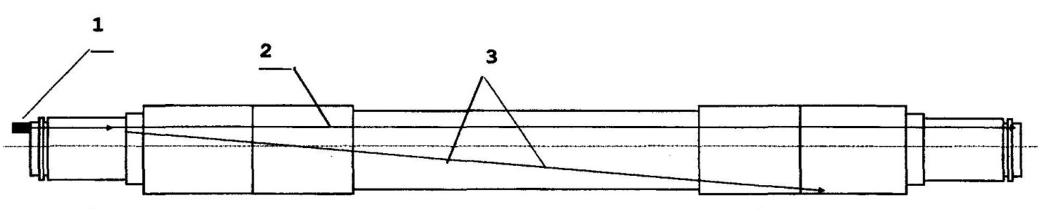
$N(l_i)$ is a number of component parts under observation at running time l_i and with account of component parts failed to running time l_i;

k is a number of component parts, failed to running time l_i.

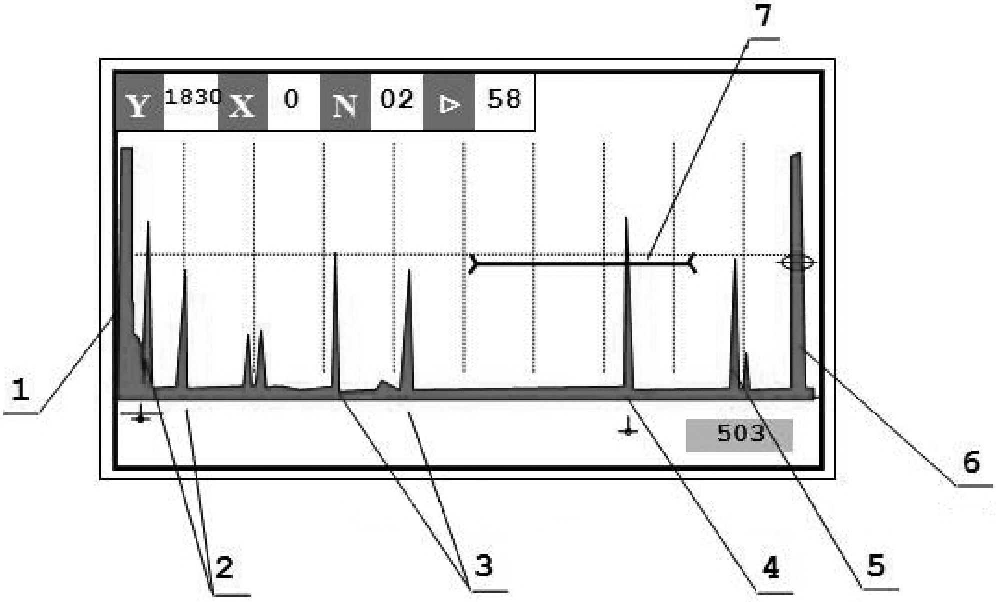
A set of point estimates of the probability of failure of a component part, obtained at different running time, makes it possible to construct an empirical dependence on its running time (empirical function of distribution of running time to failure $\hat{F}(l)$). When combining information of n samples, each of which represents N component parts of the same name submitted to non-destructive control, we obtain a sample n×N of sufficiently large volume,



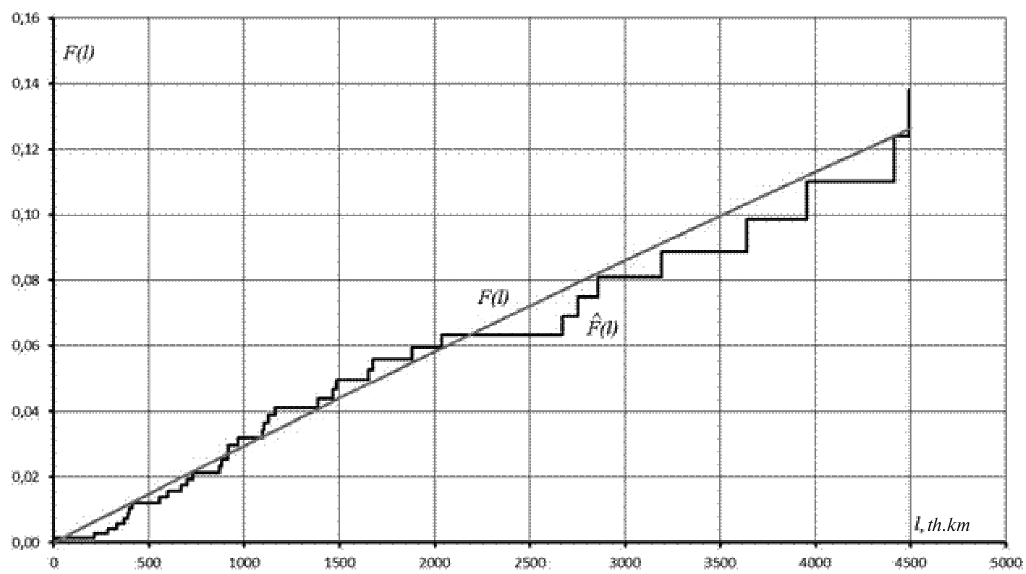
Pic. 2. Ordered series of running time of sample of N component parts submitted to non-destructive control, and empirical function of probability of failure.



Pic. 3. Acoustic control scheme of a far axle set of a wheel set of an electric locomotive VL80 and evaluation of an axle on «ensoundness» (ed.note: term of the authors to define the level of propagation of sound signal through the controlled axle).
1 – direct converter; 2 – axis of an ultrasonic beam; 3 – «side» beams.



Pic. 4. Signals on the screen of the ultrasonic flaw detector UD2–102:
1 – leading edge of the probe pulse; 2 – signals from the edges of the bearing rings on the axle neck; 3 – interference from the edges of the wheel center and the inner fillet of an axle set (given transformation of a beam of a longitudinal wave to a cross wave); 4 – a signal from a crack in the area below the inner edge of a spider centre of a far wheel; 5 – a signal from a fillet of axle neck; 6 – «bottom» signal; 7 – control zone.



Pic. 5. Empirical and theoretical exponential function of running time distribution to failure of the wheel set axle.

which will significantly improve the accuracy of the estimation of the empirical function of running time distribution to failure.

According to representative sample of running time to failure of a considered component part, which is right truncated and received in the control process, it is necessary to determine a type and parameters of the distribution of running time to failure [1], that is to construct a theoretical function of its distribution F (l).

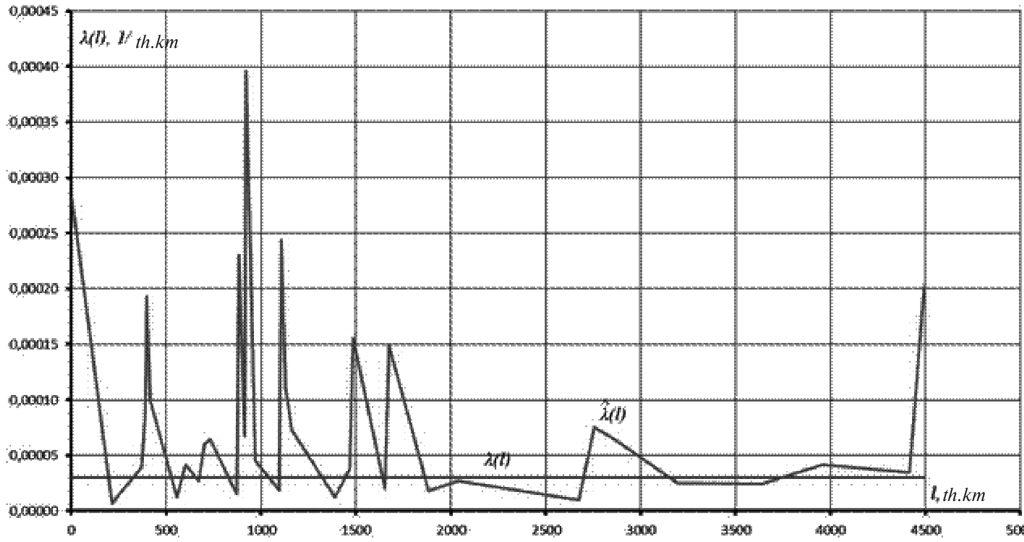
Truncation of a sample is determined by the fact that the probability, that in a sample of inspected component parts all of them will be defective, is practically zero.

With the use of the theoretical function of running time distribution to failure, it becomes possible

Table 1

Calculated values of reliability parameters of wheelsets axes of electric locomotives VL80

Running time to failure *l*, th. km	Number of wheel sets axes *N (l)*	Increment of running time Δ*l*, th. km	Increment of empirical distribution function ΔF (*l*)	Increment of the empirical function of running time density to failure Δ*f* (*l*), 1 / th. km	Calculated value of failure rate λ *(l)*, 1 / thousand. km
1	2	3	4	5	6
4,849	734	4,849	0,001362398	0,00028096	0,00028135
213,57	701	208,721	0,001426534	0,00000683	0,00000685
283	679	69,43	0,001472754	0,00002121	0,00002130
332,291	663	49,291	0,001508296	0,00003060	0,00003078
372	635	39,709	0,001574803	0,00003966	0,00003995
390,117	629	18,117	0,001589825	0,00008775	0,00008854
398,5	625	8,383	0,0016	0,00019086	0,00019289
414,9	619	16,4	0,001615509	0,00009851	0,00009972
558,114	581	143,214	0,00172117	0,00001202	0,00001219
601,45	568	43,336	0,001760563	0,00004063	0,00004127
670,432	543	68,982	0,001841621	0,00002670	0,00002717
702,517	532	32,085	0,001879699	0,00005858	0,00005974
732,9	522	30,383	0,001915709	0,00006305	0,00006442
873,329	484	140,429	0,002066116	0,00001471	0,00001506
882,6	480	9,271	0,002083333	0,00022472	0,00023058
914,798	470	32,198	0,00212766	0,00006608	0,00006795
920,366	468	5,568	0,002136752	0,00038376	0,00039550
969,95	458	49,584	0,002183406	0,00004403	0,00004548
1097,209	429	127,259	0,002331002	0,00001832	0,00001897
1107,16	428	9,951	0,002336449	0,00023480	0,00024370
1129,356	422	22,196	0,002369668	0,00010676	0,00011108
1163,952	414	34,596	0,002415459	0,00006982	0,00007283
1388,631	376	224,679	0,002659574	0,00001184	0,00001238
1467,024	354	78,393	0,002824859	0,00003603	0,00003780
1486,241	352	19,217	0,002840909	0,00014783	0,00015556
1652,679	316	166,438	0,003164557	0,00001901	0,00002007
1675,37	315	22,691	0,003174603	0,00013991	0,00014820
1884,324	281	208,954	0,003558719	0,00001703	0,00001811
2039,842	256	155,518	0,00390625	0,00002512	0,00002682
2672,298	178	632,456	0,005617978	0,00000888	0,00000954
2754,921	174	82,623	0,005747126	0,00006956	0,00007518
2857,441	163	102,52	0,006134969	0,00005984	0,00006511
3194,424	130	336,983	0,007692308	0,00002283	0,00002505
3640,6	101	446,176	0,00990099	0,00002219	0,00002462
3957,154	86	316,554	0,011627907	0,00003673	0,00004128
4414,488	72	457,334	0,013888889	0,00003037	0,00003467
4494,158	72	79,67	0,013888889	0,00017433	0,00020223



Pic. 6. Dependencies of failure rate of wheelsets axes on running time.

to determine parameters of reliability and durability [2] of a considered component part. Testing of the proposed method was performed on information about the results of NC of wheel sets axes of electric locomotives. 37 defective component parts were found out of 734 inspected component parts with different running time (from 5 to 4,5 million km). NC at the enterprises was carried out in accordance with the regulatory documentation, process chart, which is based on the standards of JSC «Russian Railways» and standard instructions for NC. Modern ultrasonic flaw detectors, in particular UD2–102 allow us to reliably determine the location of occurrence and conventional dimensions of a defect. Technique of control test provide for how to prepare a flaw detector, to tune it to a certain control zone of an axle, to install a converter on the surface of a controllable section and move it along the desired path (Pic. 3).

When there is a defect in the propagation path of the ultrasonic wave, a part of it is reflected from the defect and enters the converter, whereby a signal is displayed on a flaw detector screen as amplitude (Pic. 4).

Based on a sample of running time of wheel set axles of electric locomotives VL80 from the beginning of their operation to the time of NC, truncated empirical distribution function was calculated (Table 1, Pic. 5).

The empirical function (Pic. 5) together with the method of least squares make it possible to determine a kind and parameters of the distribution law F (l), best describing the experimental data of running time to failure [1] as a result of non-destructive control of wheel sets axes of electric locomotives.

It is found that the obtained sample of running time to failure of wheel sets on the range of their control from 0 to 4,5 million km abides by an exponential distribution law with a constant failure rate =0,00003 1 / th. km (Pic. 6).

Conclusion. *When running time of wheel sets axes reaches 4,5 million km about 14% of wheel sets axes fail. Since the speed of failures in the interval of running time under consideration remains constant, we can conclude that service lifetime of the axes of wheel sets within that range is not exhausted; they do not reach the limit state of their technical reliability.*

Keywords: *railway, traction rolling stock, non-destructive control, wheel set, locomotive, reliability, method of calculation.*

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