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Determining the Time Between Overhauls of the ZIL-131 Gearbox Based on Variations in State Parameters

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***Abstract*—*Over time, the technical state of the ZIL-131 gearbox deteriorates, leading to random failures that require inspection, maintenance, and repair. This paper introduces a state parameter method to determine the lifetime of vehicle components based on changes in state parameters during operation. The research is applied to the gearbox of the ZIL-131 vehicle. The results of this study provide a scientific basis for optimizing usage and adopting a proactive approach to maintenance*.

***Keywords*—*Technical state, Time Between Overhauls, State Parameters, Reliability*.

I. INTRODUCTION

In reality, vehicle equipment operates under complex conditions that can easily cause unexpected damage. Random failures affect the continuity of vehicle operation. Therefore, this paper proposes a solution that applies the state parameter method to estimate the time between overhauls of the ZIL-131 gearbox. Based on this approach, the method can be extended to other vehicle equipment to estimate reliability, lifetime, and time between overhauls.

II. BACKGROUND

The variation of state parameters in components and systems depends on structural factors such as manufacturing, assembly, testing, and loads, as well as usage conditions such as weather, terrain, working environment, and user operation. If we take a sample set for a specific piece of equipment and consider only structural factors, the trend of state parameter variation will follow continuous functions, as shown in Fig. 1 (dashed line). These curves follow the same pattern but have different slopes. However, if we also account for usage conditions, the variation becomes a zigzag line. In this case, the total change in the state parameter *(U)* at a given time is the sum of the theoretical change *(A)*, which depends on structural factors, and the change (Z) caused by usage conditions.

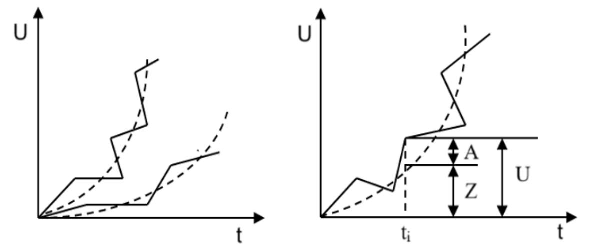

Fig. 1. Trend of State Parameter Variation Depending on Usage Time

According to [1], the value of U(t) is a complex random probability function. However, by applying suitable mathematical operations [2], we can represent U(t) as in (1):

$$U(t) = V_A . f_A(t) + V_Z . f_Z(t) \quad (1)$$

Where: $f_A(t), f_Z(t)$ is trend functions of A and Z; V_A, V_Z represent rate of changing of A and Z.

For a single equipment, $V_A = const$. Since (2) increases monotonically with usage time, and as $V_Z . f_Z(t) \geq 0$ when we increase number of sample or increase using time of the equipment, we can use (2) to predict the variation of the state parameter of the equipment.

$$U(t) = V_A . f(t) \quad (2)$$

If U_1 is a characteristic parameter for the run-in period, the state parameter transformation function $U(t)$ is constructed using either linear or nonlinear approximation functions. However, since the working state parameter change law follows a nonlinear transformation process, an exponential approximation function provides the best fit to the actual transformation process and is therefore used for the prediction.

$$U_1(t) = V_A t^{\alpha} + U_1 \quad (3)$$

To predict the average limit travel TTT, an approximation function can be used if the travel distribution function and the rate of parameter change are known. However, this method is highly complex. According to [1], to simplify the process, we use the active durability parameter B_{cd} of the elements, which has linear values ranging from 0 to 1. Through transformation (3) ($U_1(t) = V_c t^{\alpha} + U_1 \leftrightarrow U_1(t) - U_1 = V c t^{\alpha} \leftrightarrow U(t) = V c t^{\alpha}$), it is converted to $B_{cđ}$ in equation (4), where U_G represents the limit change amount, and V_C^G denotes the rate of change of the normalized state parameter.

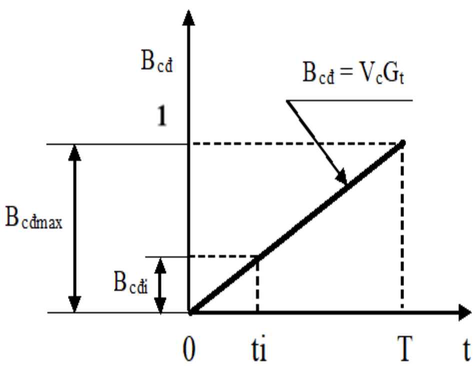

Fig. 2. Function $B_{cd} = f(t)$

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$$B_{cd} = \sqrt[a]{\frac{U(t)}{U_G}} = \sqrt[a]{\frac{V_C}{U_G}}t = V_C^G t \quad (4)$$

In order to determine the average limit of an element, its average value is first obtained from the statistical list of the series data (5). Before doing so, it is necessary to determine the action limit of element i (T_i).

$$T = \frac{1}{n}\sum_1^n T_i = \frac{1}{n}\sum_1^n \frac{t_i}{B_{cdi}(t)} \quad (5)$$

Where: P_0, P(t), P_G are respectively measured value at initial time, value at time t and limited value.

$$U(t) = U_1(t) - U_1 = (P(t) - P_0) - U_1$$
$$U_G = U_{1G} - U_1 = (P_G - P_0) - U_1 \quad (6)$$

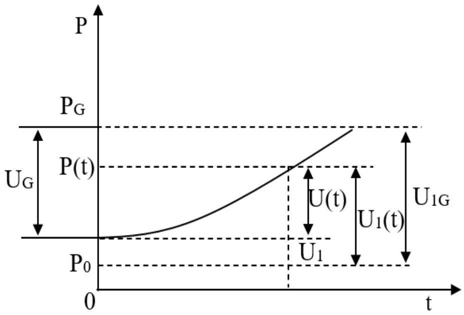

Fig. 3. Parameters of the method

III. Algorithm to Estimate the Time Between Overhauls of ZIL-131 Gearbox

To determine the average limit stroke *T* for an element, we first select the characteristic state parameters and determine the required number of test elements. Then, we measure the state parameter values of the test elements and process the results according to the following sequence:

Step 1: Create statistical values for the characteristic state parameter. Measure Pi(t) and record ti(t)nfor each element. Then, sort Pi in ascending order and calculate the corresponding rate of change: $U_{1i}(t) = |P_i(t) - P_0|$

Step 2: Establish an approximate function by identifying its parameters Va, a and U1 as in (3).

Step 3: Determine the time between overhauls T and dispersion coefficient V

$$T = \frac{1}{n-(a-1)}\sum_{i=a}^{n} T_i = \frac{1}{n-(a-1)}\sum_{i=a}^{n} t_i\sqrt{\frac{U(t)}{U_G}} \quad (7)$$

$$U_{1i}(t) = |P_i(t) - P_0| \quad (8)$$

Where: a-1: Number of measurements within the first stroke when determining U_1; n: Number of samples

IV. Experiment

The experimental object was selected to determine the average limit stroke of the ZIL-131 vehicle gearbox (Table 1). A characteristic parameter of the gearbox is considered: the free rotation angle of the output shaft at 1st gear. The standard value is $P_0 = 2^0$, and the critical value is $P_G = 17^0$ for this characteristic parameter. The number of test samples is n = 41. The values of the state parameters are shown in Table I.

TABLE I. Statistical input value.

S. No.	Milestone t_i (km)	P_i (t) (deg)	Increment value $U_{1i}(t)=P_i(t)-P_0$ (deg)
1	2100	2.1	0.1
2	3270	2	0
3	4650	2.8	0.8
4	4650	2.9	0.9
5	7410	3.2	1.2
6	8780	3.3	1.3
7	10160	3.5	1.5
8	11540	3.6	1.6
9	14290	3.4	1.4
10	14290	4	2.0
11	14290	4.2	2.2
12	15670	4.6	2.6
13	18430	4.7	2.7
14	19800	4.8	2.8
15	21180	5	3.0
16	22560	5.2	3.2
17	22560	5.4	3.4
18	25310	5.6	3.6
19	26690	5.8	3.8
20	28070	6	4.0
21	29450	7	5.0
22	30820	6.1	4.1
23	32200	6.3	4.3
24	33580	6.3	4.3
25	34960	6.4	4.4
26	37710	6.5	4.5
27	37710	7	5.0
28	39090	7.3	5.3
29	40470	7.4	5.4
30	41840	7.2	5.2
31	43220	7.3	5.3
32	44600	7.6	5.6
33	45980	7.2	5.2
34	47350	7.2	5.2
35	48730	7.7	5.7
36	50110	7.6	5.6
37	51490	7.5	5.5
38	52860	7.8	5.8
39	54240	7.8	5.8
40	55620	7.9	5.9
41	56800	8.3	6.3

TABLE II. Milstone definition

S. No.	1	2	3	4	5	6	7
Milestone	**2000-9857**	**9857-17714**	**17714-25571**	**25571-33429**	**33429-41286**	**41286-49143**	**49143-5700**
Increment value	0.1	1.5	2.7	3.8	4.3	5.2	5.6
	0	1.6	2.8	4	4.4	5.3	5.5
	0.8	1.4	3	5	4.5	5.6	5.8
	0.9	2	3.2	4.1	5	5.2	5.8
	1.2	2.2	3.4	4.3	5.3	5.2	5.9
	1.3	2.6	3.6		5.4	5.7	6.3
No. Samples	**n = 6**	**n = 6**	**n = 6**	**n = 5**	**n = 6**	**n = 6**	**n = 3**
Medium Increment value	**0.712**	**1.883**	**3,117**	**4,24**	**4.817**	**5.367**	**5.817**
Medium Milestone	**5143.3**	**13373**	**21640**	**29446**	**37253**	**45287**	**53520**

Parameter U_1 is determined using the 3-point method according to [3]. The survey object is at t_0 = 9857km with $U_0 = 1.385^0$ and at t_3 = 25571km with $U_3 = 3.682^0$, from which we deduce $t_2 = \sqrt{t_0 t_3}$ = 15876km with $U_2 = 2.257^0$. Using the above formula, we obtain as in (9):

$$U_1 = \frac{U_0 U_3 - U_2^2}{U_0 + U_3 - 2U_2} = 0.012^0 \qquad (9)$$

TABLE III. Identify parameters used to estimate α and mv

S. No. j	Milestone tj	X_j=lnt_j	U_{1j}	U_{1j}-U_1	Y_j= ln(U_{1j}-U_1)
1	5143.3	8.545	0.717	0.705	-0.350
2	13373	9.501	1.883	1.871	0.627
3	21640	9.982	3.117	3.104	1.133
4	29446	10.290	4.24	4.228	1.442
5	37253	10.525	4.817	4.804	1.569
6	45287	10.721	5.367	5.355	1.678
7	53520	10.888	5.817	5.805	1.759
$\sum_{j=1}^{7}$		**70.453**			**7.857**

S. No. j	$X_j - \overline{X}$	$Y_j - \overline{Y}$	$(X_j - \overline{X}).(Y_j - \overline{Y})$	$(X_j - \overline{X})^2$
1	-1.519	-1.472	2.237	2.308
2	-0.564	-0.496	0.279	0.318
3	-0.082	0.010	-0.001	0.007
4	0.225	0.319	0.072	0.051
5	0.461	0.447	0.206	0.212
6	0.656	0.555	0.364	0.430
7	0.823	0.636	0.524	0.677
$\sum_{j=1}^{7}$			**3.682**	**4.004**

From parameters in table III, we can obtain α as in (10):

$$a = \frac{\sum_{j=1}^{7}(X_j - \overline{X})(Y_j - \overline{Y})}{\sum_{j=1}^{7}(X_j - \overline{X})^2} \approx 1 \qquad (10)$$

$$lnV_A = \overline{Y} - a\overline{X} \rightarrow V_A = 2.936.10^{-4} \qquad (11)$$

Finally, we get the approximate function: $U_1(t) = 2.936.10^{-4}.t^1 + 0.012$

TABLE IV. Identify parameters used to estimate *T and V*

S. No. j	t_i	$u_i(t)$	$T_i = t_i\left[\frac{u_G}{u_i(t)}\right]^{1}$	$\left(\frac{T_i}{T} - 1\right)^2$
7	10160	1.488	125234	0.0025
8	11540	1.588	132531	0.0000
9	14290	1.388	189984	0.1952
10	14290	1.988	128543	0.0006
11	14290	2.188	115818	0.0147
12	15670	2.588	105809	0.0388
13	18430	2.688	119419	0.0088
14	19800	2.788	123300	0.0041
15	21180	2.988	122322	0.0051
16	22560	3.188	121429	0.0062
17	22560	3.388	113655	0.0189
18	25310	3.588	119799	0.0083
19	26690	3.788	119095	0.0092
20	28070	3.988	118437	0.0102
21	29450	4.988	97424	0.0679
22	30820	4.088	126585	0.0015
23	32200	4.288	125559	0.0022
24	33580	4.288	130940	0.0000
25	34960	4.388	132947	0.0001
26	37710	4.488	139933	0.0038
27	37710	4.988	124749	0.0028
28	39090	5.288	121357	0.0062
29	40470	5.388	123107	0.0043
30	41840	5.188	132619	0.0000
31	43220	5.288	134179	0.0003
32	44600	5.588	130399	0.0001
33	45980	5.188	145742	0.0112
34	47350	5.188	150084	0.0193
35	48730	5.688	139752	0.0037
36	50110	5.588	146509	0.0125
37	51490	5.488	153529	0.0273
38	52860	5.788	148751	0.0166
39	54240	5.788	152634	0.0251
40	55620	5.888	153629	0.0275
41	56800	6.288	146067	0.0118
Total			**4611870**	**0.56715**

Follow equations (7) and (8), we can identify the time between overhauls T=131767Km and dispersion coefficient V = 0.016681

V. Conclusion

By this method, it is possible to predict the average limit travel of elements (such as components, joints, assemblies, systems, or equipment) in vehicles with similar structures. This is achieved by determining characteristic parameters as input variables for the survey model, including characteristic values Pi corresponding to usage time t_i, the initial value P_0, and the limit value P_G, along with the random operating conditions of the element. Measurements are conducted on a sufficiently large number of samples to ensure accuracy. Additionally, this method can serve as a basis for determining appropriate maintenance and repair cycles tailored to the actual operating conditions of the equipment

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