METHODS FOR DETERMINING THE RELIABILITY INDICATORS OF VIBRATION SITES

Maksym Delembovskyi
Ph.D., Associate Professor of the Department of Machines and Equipment Technological Processes Kyiv National University of Construction and Architecture, UKRAINE

Oleksandr Diachenko
Ph.D., Assistant of the Department of Machines and Equipment Technological Processes Kyiv National University of Construction and Architecture, UKRAINE

Summary. The work is devoted to the issues of experimental research in order to ensure further effective improvement of the reliability of vibration sites. Today the problem is to determine the optimal margin of safety when calculating the strength depending on the predicted reliability criteria.

Keywords: vibrating machine, criteria, design, operation, repair, faultlessness, faulty, workable, inoperable.

According to the procedure of conducting experimental research, in order to obtain information on the operation of vibration platforms (sites) for failure, the corresponding fixation of the failure was carried out with fixation in special tables. The obtained fault data were recorded by groups of prefabricated units, parts and elements, in order to separately determine the data on the time of their operation. According to these data, we analyzed the development of the main elements of failure and those that most often failed [1-7].

The research identified the main prefabricated units and parts that failed: engine, gearbox, synchronizer, vibrator, propeller shafts, couplings (Fig. 1). At the same time cardan shafts, couplings most often failed. In some cases, the destruction of bearings in vibrators has been demonstrated.
The working body is an element of the construction of vibrating platforms, which instead can consist of individual elements, such as a vibrating tube or a form, as well as a welded frame. During researches in this group of elements frequent defects owing to contact of vibrotumbs with the form were found (fig. 2).

The method of research on the development of parts to failure was to conduct an experiment in real operating conditions of vibrating platforms VB-10V [2].

Due to the frequent fixation of the detected failures of the cardan shafts of vibrating platforms, it was decided to apply the appropriate algorithm in the calculation of such an element of vibrating platforms with subsequent fixation of the failure time [7-8].

<table>
<thead>
<tr>
<th>Operating time on failure of cardan shafts</th>
<th>Operating time on failure, h.</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>148</td>
</tr>
<tr>
<td>130</td>
<td>155</td>
</tr>
<tr>
<td>150</td>
<td>157</td>
</tr>
<tr>
<td>162</td>
<td>178</td>
</tr>
<tr>
<td>167</td>
<td>184</td>
</tr>
<tr>
<td>186</td>
<td>188</td>
</tr>
<tr>
<td>199</td>
<td>215</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>126</td>
</tr>
<tr>
<td></td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>145</td>
</tr>
<tr>
<td></td>
<td>175</td>
</tr>
<tr>
<td></td>
<td>195</td>
</tr>
<tr>
<td></td>
<td>202</td>
</tr>
<tr>
<td></td>
<td>209</td>
</tr>
<tr>
<td></td>
<td>252</td>
</tr>
<tr>
<td></td>
<td>242</td>
</tr>
<tr>
<td></td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>164</td>
</tr>
<tr>
<td></td>
<td>166</td>
</tr>
<tr>
<td></td>
<td>192</td>
</tr>
<tr>
<td></td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>242</td>
</tr>
<tr>
<td></td>
<td>127</td>
</tr>
<tr>
<td></td>
<td>133</td>
</tr>
<tr>
<td></td>
<td>141</td>
</tr>
<tr>
<td></td>
<td>163</td>
</tr>
<tr>
<td></td>
<td>182</td>
</tr>
<tr>
<td></td>
<td>239</td>
</tr>
</tbody>
</table>
Construction of a statistical series of information. In the process of studying the patterns of distribution of continuous random variables, sometimes there is a need for a large number of observations. In this case (of course, if \( N > 30 \)) the values observed in the variation series are grouped, and the whole series of values of the observed feature from \( t_1 \) to \( t_n \) is divided into a number of disjoint intervals, and then not individual values are considered [7-8].

The number of intervals is determined from the condition of identifying the regularity of the distribution of values of the indicator depending on the sample size \( N \). The larger the amount of information, the greater the number of intervals taken. If the number of intervals is large, the distribution pattern will be distorted by the absence of experimental points in individual intervals, and in the case of a small number of intervals, the characteristic features of the distribution will be smoothed. Only the correct choice of the interval gives an idea of the law of distribution of a random variable [1].

The number of intervals was determined by the formula:

\[
K = \sqrt{N},
\]

where:

\( N \) – this is the sample size.

The expression obtained after the calculation is rounded up to the nearest integer.

All intervals for the convenience of further calculations are taken equal, integer and without gaps.

However, in some cases, when processing statistics that are distributed rather unevenly, it is sometimes convenient to choose narrower intervals in the area of the highest distribution density than in the area of the lowest.

The value of the interval was determined by the formula:

\[
h = \frac{T_{\text{max}} - T_{\text{min}}}{K - 1},
\]

where:

\( T_{\text{max}} \) and \( T_{\text{min}} \) – respectively, the largest and smallest values of reliability indicators in the summary table of information.

The number of intervals depends on the sample size \( N \).

The left and right boundaries of the distribution area are shifted by \( 0.5h \) and are taken respectively:

\[
t_0 = T_{\text{min}} - 0.5h
\]

\[
t_k = T_{\text{max}} + 0.5h
\]
where:
\( t_0 \) – the left border of the first interval;
\( t_k \) – the right limit of the last interval.

If necessary, the left extreme limit can be set. In subsequent calculations, it was not the values of the interval limits that were used, but their mean value:

\[
t_{\text{mp}} = \frac{t_{i-1} + t_i}{2},
\]

where:
\( t_i \) – the value of the right boundary of the \( i \)-th interval.

After determining the boundaries of the intervals of the group count the frequencies and the number of observations that fall into each of the intervals \([h_i]\), \( i = 1, K \).

The sum of the frequencies of all intervals is equal to the sample size:

\[
\sum_{i=1}^{k} n_i = N = 50
\]

Another characteristic of the statistical distribution is the frequency \( P_i \) (relative frequency), which is determined for each interval by the ratio of the frequency \( n_i \) to the total number of observations \( N \):

\[
\tilde{P} = \frac{n_i}{N}.
\]

Determining the empirical density of resource allocation \( f_i(t) \) in the \( i \)-th interval \( i = 1, 2, 3 \ldots \):

\[
f_i(t) = \frac{n_i}{N \cdot h_i}.
\]

Definition of empirical function:

\[
F_2(t) = \tilde{P}_1 + \tilde{P}_2;
\]

\[
\vdots
\]

\[
F_k(t) = \sum_{i=1}^{k} \tilde{P}_i.
\]

Using the data from table 2, determine the main statistical characteristics of the sample.

The average value of the resource \( T_{pcp} \), found by the formula:

\[
T_{p\cdot cp} = \frac{\sum_{i=1}^{k} t_{p} n_i}{N}
\]

To determine the standard deviation of the studied value (resource) \( \sigma \) used the formula:
Table 2

<table>
<thead>
<tr>
<th>Interval number</th>
<th>Interval limits</th>
<th>The middle of the interval $t_{cp}$</th>
<th>Frequency $n_i$</th>
<th>$t_{cp}^2$</th>
<th>$t_{cp}n_i$</th>
<th>$t_{cp}^2n_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>111.25-138.75</td>
<td>125</td>
<td>7</td>
<td>19251.6</td>
<td>971.25</td>
<td>134761.2</td>
</tr>
<tr>
<td>2</td>
<td>138.75-166.25</td>
<td>152.5</td>
<td>10</td>
<td>27639.1</td>
<td>1662.5</td>
<td>276391</td>
</tr>
<tr>
<td>3</td>
<td>166.25-193.75</td>
<td>180</td>
<td>8</td>
<td>37539.1</td>
<td>1550</td>
<td>30312.8</td>
</tr>
<tr>
<td>4</td>
<td>193.75-221.25</td>
<td>207.5</td>
<td>6</td>
<td>48951.6</td>
<td>1327.5</td>
<td>293709.6</td>
</tr>
<tr>
<td>5</td>
<td>221.25-248.75</td>
<td>235</td>
<td>7</td>
<td>61876.6</td>
<td>1741.25</td>
<td>433136.2</td>
</tr>
<tr>
<td>6</td>
<td>248.75-276.25</td>
<td>525</td>
<td>7</td>
<td>76314.1</td>
<td>1933.75</td>
<td>534198.7</td>
</tr>
<tr>
<td>7</td>
<td>276.25-303.75</td>
<td>580</td>
<td>5</td>
<td>92264.1</td>
<td>1518.75</td>
<td>461320.5</td>
</tr>
</tbody>
</table>

$\sum=50$  $\sum=10705$  $\sum=2433830$

Next, calculations were performed using the sum method (Table 3).

Defined auxiliary intervals:

$$\mu_i = k_i - \lambda_i$$  (12)

The average value of the resource $T_{p,cp}$, hours, found by the formula:

$$T_{p,cp} = \frac{\sum t_{cp} - \frac{h\mu_i}{N}}{N}.$$  (13)

To determine the standard deviation of the studied value (resource) using the formula:

$$\sigma = h\sqrt{\frac{\mu_i - \mu_i^2}{N}}.$$  (14)

Table 3

<table>
<thead>
<tr>
<th>Interval number</th>
<th>The middle of the interval $t_{cp}$</th>
<th>Frequency $n_i$</th>
<th>$K_1=110$</th>
<th>$K_2=84$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>125</td>
<td>7</td>
<td>7</td>
<td>---</td>
</tr>
<tr>
<td>2</td>
<td>152.5</td>
<td>10</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>3</td>
<td>180</td>
<td>8</td>
<td>33</td>
<td>---</td>
</tr>
<tr>
<td>4</td>
<td>207.5</td>
<td>6</td>
<td>25</td>
<td>61</td>
</tr>
<tr>
<td>5</td>
<td>235</td>
<td>7</td>
<td>19</td>
<td>36</td>
</tr>
<tr>
<td>6</td>
<td>525</td>
<td>7</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>7</td>
<td>580</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

$\hat{\lambda}_1 = 94$  $\hat{\lambda}_2 = 119$

Determined the coefficient of variation:

$$V = \frac{\sigma}{T_{p,cp}}.$$  (15)

The actual value of the criterion $\lambda$ for the endpoints is determined:
\[ \lambda_p = \frac{1}{\sigma_t} (t_j - t_{j-1}) \quad j = 1, N \]  

(16)

where: \( t_j \) and \( t_{j-1} \) – adjacent information points. The condition is fulfilled \( \lambda_p < \lambda_t \).

Thus, as a result of checking the information on the drop-down points, it was found that the minimum and maximum values of the sample \( t_{\min} = 125 \) and \( t_{\max} = 126 \) with probability \( \gamma = 0.95 \).

Definition of laws and parameters of distribution. An empirical integral distribution function, \( \hat{f}(t) \) histogram or empirical distribution density curve is used as a graphical representation of a statistical series of random variables \( \hat{P}(t) \) [7].

In practical calculations, preference was given to the relative frequency histogram, because it is used to plot the empirical density of the distribution of points with coordinates \( [t_{cp}, \hat{f}(t_i)] \).

From this histogram it is seen that in this case the Weibull distribution law is correct. Therefore, considering this law, it is necessary to consider the Normal law of distribution, because they are similar, and at first glance they can be confused (Fig. 3):

According to Weibull's distribution law:

\[ f(t) = \frac{b}{a} \left( \frac{t}{a} \right)^{b-1} \exp \left[ -\left( \frac{t}{a} \right)^b \right], \]

(17)

where:

\( a \) and \( b \) – distribution parameters \( a > 0; \ b > 0 \).

It is established that \( \chi^2 \) Pearson's criterion for a large number of observations minimizes errors, which differs favorably from other criteria of agreement:

\[ \chi^2 = N \cdot h_i \sum_{i=1}^{k} \left[ \frac{f(t_i) - f(t_{cp_i})}{f(t_{cp_i})} \right]^2; \]

(18)

where:

\( N \) – total number of observations;

\( h_i \) – the width of the i-th interval;
\( k \) - number of splitting intervals;
\( \tilde{f}(t_i), f(t_i) \) - respectively, the empirical and theoretical density of the probability distribution;
\( t_{cp} \) - the middle of the \( i \)-th interval for a continuous random variable or possible values for a discrete one.

Therefore, it is found \( P(r, x^2) = 0.99 \) that exceeds the accepted significance level of 0.05. This gives reason to argue that the hypothesis of the empirical distribution can not be rejected

\[
P(t) = \exp \left[ -\left( \frac{t}{a} \right)^b \right].
\]

(19)

For the Weibull distribution law received characteristic dependences (20):

\[
F(t) = Q(t) = 1 - \exp \left[ -\left( \frac{t}{a} \right)^b \right].
\]

(20)

With respect to these calculations, the probability of failure and failure-free operation is constructed (Fig. 4).

Let's define \( T_r \):

\[
T_r = T_{p, cp} \cdot \left( -\ln \frac{80}{100} \right)^{\frac{1}{6}}
\]

(21)

Conclusions. The results of the research indicate a low level of reliability of the cardan shaft, which leads to a long downtime at an unscheduled time of repair, which is 0.8-1.2 hours. in the presence of spare parts in stock.

As a result of processing the statistical information of the cardan shaft reliability indicators, it was found that the average resource is 262 hours, the standard deviation is equal to \( \sigma = 53.2 \) hours, the coefficient of variation \( V = 0.27 \).

The hypothesis of the error of the empirical distribution of resource indicators in comparison with Weibull's theoretical law is put forward.
The parameters of Weibull's distribution law are determined, and graphs for the model of reliability and failures of cardan shafts, graphs of regularities of distribution of resource indicators $P(t)$ and distribution functions $F(t)$ are used in the developed recommendations.

References:
[4] Делембовський, М., Терентьєв, О., & Шабала, Є. (2020). Технологія впровадження середовища matlab в дослідженні моделі загроз інформаційної безпеки. ЛОГОΣ. ОНЛАЙН. https://doi.org/10.36074/2663-4139.15.08