Reliability indexes of vibrating platforms for compaction of construction mixtures

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Abstract. In the article of experimental research and a particularly important prerequisite is to establish the required values with the least error, because the reliability of the information obtained from the processing of experiments is key to determine the true value of a parameter. According to the results of the study, data were obtained on the actual operating time for failure of the elements of the vibrating platforms VB-10V. The research identified the main prefabricated units and parts that failed: motor, gearbox, synchronizer, vibrator, propeller shafts, clutches. At the same time, cardan shafts and couplings failed the most. In some cases, the destruction of bearings in vibrating exciters has been demonstrated. The method of determining the number of experiments and estimating the error in measuring the studied parameters is based on the basic provisions of probability theory and mathematical statistics. 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 261.95 hours, the standard deviation is 53.2 hours, the coefficient of variation is 0.27.

1. Introduction
Vibrating machines are widely used in the construction industry in the manufacture of concrete and reinforced concrete products [1]. Vibrating platforms occupy a dominant place among vibrating machines [2]. The efficiency of their work largely depends on a fairly specific consideration of the forces of the system and the reliability of the elements of vibrating machines [3]. Improving the reliability and efficiency of vibrating machines is achieved by implementing a set of measures at all stages of creation
(design, construction, manufacture and operation) of vibrating machines [4]. One of the important aspects of ensuring the reliability of vibrating machines is to determine the failure time of the machine elements during operation [5] and develop appropriate recommendations on this basis [6]. However, at the present stage, recommendations for the reliability of vibration technology are virtually absent [7]. Therefore, the study of reliability at the stage of operation of vibrating machines is an urgent task, which is the subject of these studies [8]. A characteristic feature of the technology of manufacturing reinforced concrete products is the use in laying [9] and compaction of the concrete mixture of a large fleet of different designs of the performance of vibrating machines and mechanisms [10].

Existing machines and mechanisms, widely used in this industry [11], highly productive and technologically and economically efficient [12], very often do not meet hygienic requirements [13]. The specifics of work in the construction industry has necessitated an in-depth study of the effects of vibration [14], noise and other additional factors that aggravate the general health of workers and deteriorating working conditions [15].

Workers and operators servicing vibroforming equipment can be exposed to such dangerous and unfavorable actors as the danger of electric shock, injuries when moving loads, adverse effects of microclimate and dust, harmful effects of vibration and noise [16]. If the influence of the first four factors are mostly episodic and, with proper organization of work can be minimized, the last two factors require considerable effort to bring the parameters of noise and vibration to sanitary standards [17].

Analysis of the characteristics of noise and vibration of vibrating platforms without form, when there are no obvious sources of shocks, shows that significant levels of sound pressure occur not only at vibration frequency [18], but also in the medium and high frequencies, where there is a number of pronounced maxima, which determines the harmfulness of noise [19]. This suggests that the individual components of the molding units are imperfect, that they are dynamic processes and, above all, microshocks, which create multi-frequency oscillations of the metal surfaces of the site [20].

Additional studies have shown that when the molding units are not in a stable mode [21], there may be a collision of the concrete mass and the bottom of the metal mold [22], and the frequency of collisions may not be with the main operating frequency of the vibrating platform [23]. If the thickness of the molded products is the same height of the mold [24]. If the mass distribution of concrete on the bottom surface is uneven, the separation of concrete from the mold causes deformation oscillations of the bottom and creates additional noise [25]. A significant source of noise at medium and high frequencies is the drive [26]. The noise of electric motors is determined by power, number of revolutions and depends on the degree of wear of bearings, rotor balancing, the degree of perfection of the electromagnetic system and the type of blowing [27]. Used on vibrating platforms, the total noise level is 95-100 dB.

2. The aim and objective of research
The aim of the work is to study the parameters and failure characteristics of the elements of the vibrating machine at the stage of operation to develop recommendations for determining the reliability of components and parts.

To achieve this aim, the following tasks are formulated and solved: assessment and analysis of the state of reliability of vibration sites; experimental studies were carried out on vibrating platforms operating in the factory to determine the failure time of their prefabricated units and parts.

3. Materials and methods
In the methods of experimental research, a particularly important prerequisite is the establishment of the required values with the least error, because the reliability of the information obtained from the processing of experiments is key to determine the true value of a parameter. According to the results of the study, data were obtained on the actual operating time for the failure of the elements of the vibrating platforms. The method of determining the number of experiments and estimating the error in measuring the studied parameters is based on the basic provisions of probability theory and mathematical statistics.

According to the procedure for conducting experimental studies to obtain information on the operation of vibrating platforms for failure, the corresponding fixation of the failure was carried out with
the fixation in special tables. The obtained fault data were recorded by groups, prefabricated units, parts
and elements in order to separately determine the data on the time of their operation. According to these
data, the analysis of the development of the main elements of failure and which most often failed. The
research identified the main prefabricated units and parts that failed: engine, gearbox, synchronizer,
vibrator, propeller shafts, couplings. At the same time, cardan shafts and couplings failed the most. In
some cases, the destruction of bearings in vibrating exciters has been demonstrated. The working body
is an element of the construction of vibrating platforms, which in turn can consist of individual elements
such as a vibrating tube or form and a welded frame. During researches from this group of elements
frequent defects owing to contact of vibrotombs with the form were found (figure 1). The method of
research on the operation of parts to failure was to conduct an experiment in real operating conditions
of vibrating platforms VB-10V.

Figure 1. Photo-fixation of failures of working bodies of vibrating platforms.

Due to the most frequent fixation of detected failures, namely the propeller shafts of vibrating
platforms, it was decided to apply the appropriate calculation algorithm on this element of vibrating
platforms with subsequent fixation of the failure time (table 1).

Table 1. Operating time for failure of cardan shafts.

| Operating time on failure, hours |
|--------------------------------|
| 125; 148; 126; 131; 127; 130; 155; 135; 164; 133; 150; 157; 145; 166; 141; 162; 178; 175; 192; 163;
| 167; 184; 195; 200; 182; 186; 188; 202; 242; 239; 199; 215; 209; 252; 242; 222; 226; 268; 261; 271;
| 225; 236; 272; 275; 288; 287; 269; 280; 288; 290. |

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 to conduct 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. The number of intervals is determined from the
condition of detecting the regularity of the distribution of values of the indicator depending on the
sample size \(N\). The larger the amount of information, the more intervals are 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. The number of intervals was determined by the formula: \( K = N^{1/2} = 50^{1/2} \approx 7 \), where \( N \) – 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 non-discontinuous. 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 values of the interval were determined by the formula:

\[
h = (T_{\text{max}} - T_{\text{min}}) \cdot (K - 1)^{-1} = (290 - 125) \cdot (7 - 1)^{-1} = 27.5,
\]

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 0.5\( h \) and taken accordingly:

\[
t_0 = T_{\text{min}} - 0.5h = 125 - 0.5 \cdot 27.5 = 111.25, t_k = T_{\text{max}} + 0.5h = 290 + 0.5 \cdot 27.5 = 303.75,
\]

where \( t_0 \) – the left boundary of the first interval; \( t_k \) – the right limit of the last interval.

The distribution limits were determined by the formula: \( t_i = T_0 + i \cdot h \).

4. Results and discussion

Having obtained the appropriate number of intervals, found the number of hits in each range. If necessary, the left extreme limit can be specified. In subsequent calculations, it was not the values of the interval limits that were used, but their mean value \( t_{\text{sr}} = (t_{i-1} + t_i) \cdot 2^{-1} \), where \( t_i \) – the value of the right boundary of the \( i \)-interval. After determining the boundaries of the intervals of the group count the frequencies and the number of observations that occurred in each of the intervals \([h_i]_i, i = 1, K \). 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 \( P_t \) (relative frequency), which is determined for each interval by the ratio of the frequency \( n_i \), to the total number of observed \( N \):

\[
P_t = n_i \cdot (N \cdot h_i)^{-1}
\]

Determination of the empirical density of resource allocation \( f(t) = n_i \cdot (N \cdot h_i)^{-1} \) in the \( i \)-th interval \( i = 1, 2, 3, \ldots \). Using the data from table 2, determine the main statistical characteristics of the sample.

**Table 2.** Numerical values of distribution parameters.

| Interval | Range      | \( t_{\text{sr}} \) | \( n_i \) | \( t^2_{\text{sr}} \) | \( t_{\text{sr}} \cdot n_i \) | \( t^2_{\text{sr}} \cdot n_i \) |
|----------|------------|---------------------|----------|---------------------|-------------------------------|---------------------------------|
| 1        | 111.25-138.75 | 125                | 7        | 19251.6             | 971.25                        | 134761.2                       |
| 2        | 138.75-166.25 | 152.5              | 10       | 27639.1             | 1662.5                        | 276391                         |
| 3        | 166.25-193.75 | 180                | 8        | 37539.1             | 1550                          | 300312.8                       |
| 4        | 193.75-221.25 | 207.5              | 6        | 48951.6             | 1327.5                        | 293709.6                       |
| 5        | 221.25-248.75 | 235                | 7        | 61876.6             | 1741.25                       | 433136.2                       |
| 6        | 248.75-276.25 | 525                | 7        | 76314.1             | 1933.75                       | 534198.7                       |
| 7        | 276.25-303.75 | 580                | 5        | 92264.1             | 1518.75                       | 461320.5                       |
|          | \( \Sigma = 50 \) |                    |          | \( \Sigma = 10705 \) | \( \Sigma = 2433830 \)        |                                |

The average value of the resource \( t_{\text{sr}} \), found by the formula:

\[
T_{\text{sr}} = N^{-1} \cdot \sum_{i=1}^{K} (t_{\text{sr}} \cdot n_i) = 50^{-1} \cdot 10705 = 214.1 \text{ hours}.
\]

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

\[
\sigma = \left(-T^2_{\text{sr}} + N^{-1} \cdot \sum_{i=1}^{K} (t^2_{\text{sr}} \cdot n_i) \right)^{1/2} = (-214.1^2 + 50^{-1} \cdot 2433830)^{1/2} = 53.2 \text{ hours}.
\]

Then performed calculations using the sum method. Defined auxiliary intervals:

\[
\mu_1 = k_1 - \lambda_1 = 7 - 94 = -87, \quad \mu_2 = k_1 + \lambda_1 + 2 \cdot (k_2 + \lambda_2) = 7 + 94 + 2 \cdot (0 + 119) = 339.
\]
The average value of the resource $T_{sr1}$, found by the formula:

$$T_{sr1} = T_{sr} - h \cdot \mu_1 \cdot N^{-1} = 214.1 - 27.5 \cdot (-87) \cdot 50^{-1} = 261.95 \text{ hours.}$$

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

$$\sigma_t = h \cdot (N^{-1} \cdot [\mu_2 - N^{-1} \cdot \mu_1^2])^{1/2} = 27.5 \cdot (50^{-1} \cdot [339 - 50^{-1} \cdot (-87)^2])^{1/2} = 53.2 \text{ hours.}$$

Determined the coefficient of variation:

$$V = \frac{\sigma_t}{T_{sr1}} = 53.2 \cdot 261.95^{-1} = 0.203.$$ 

Next, the check for drop-down points. The actual value of the criterion $\lambda_r$ for the extreme points is determined:

$$\lambda_r = \sigma_t^{-1} \cdot (t_j - t_{j-1}), j = 1, N, \ \lambda_r = 53.2^{-1} \cdot (126 - 125) = 0.018,$$

where $t_j$ and $t_{j-1}$–adjacent information points.

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 $t_{j-1} = 125$ and $t_j = 126$ with a probability $\gamma = 0.95$. Definition of laws and parameters of distribution. An empirical integral distribution function $\hat{f}(t)$, a histogram or an empirical distribution density curve is used as a graphical representation of a statistical series of random variables $P(\hat{t})$. In practical calculations, preference was given to the histogram of relative frequencies, because it is used to plot the empirical density of the distribution of points with coordinates $[t_{sr}, \hat{f}(t)]$. From this histogram it is seen that in this case the Weibull distribution law is correct.

Therefore, when considering this law, the normal law of distribution should be considered, because they are similar, and at first glance they may be confused. According to the Weibull distribution law:

$$f(t) = b \cdot a^{-1} \cdot (t \cdot a^{-1})^{b-1} \cdot \exp[-(t \cdot a^{-1})^b],$$

where $a$ and $b$ – distribution parameters $a \gg 0, b \gg 0, K_b = 0.909, c_b = 0.245$.

$$b = 4.18, a = \sigma_t \cdot c_b^{-1} = 53.2 \cdot 0.245^{-1} = 217.14.$$ 

The agreement between the empirical and theoretical distribution was checked (figure 2).

Figure 2. Graph of consistency of empirical and theoretical distribution.

It is established that Pearson’s criterion $\chi^2$ with a large number of observations minimizes errors, which differs favorably from other criteria of agreement. Determined the degree of freedom $r$, according to the formula $r = k - S - 1 = 7 - 2 - 1 = 4$, where $k$ – number of splitting intervals; $S$ – the number of parameters of the theoretical distribution function. Therefore, it is established that $P(r, \chi^2) = 0.99,$
which exceeds the accepted level of significance of 0.05. This gives us reason to argue that the hypothesis that the empirical distribution belongs cannot be rejected. Weibull’s distribution law was characterized by dependences. With respect to these calculations, the probability of failure and failure-free operation is constructed (figure3).

\[ P(t) = 1 - \exp\left(-\frac{t}{\lambda}\right)^k \]

\[ T_{80\%} = T_{str} \cdot (-\ln(80 \cdot 100^{-1}))^{1/b} = 261.95 \cdot (-\ln(0.8))^{1/0.18} = 152.969 \text{ hours.} \]

5. Conclusion

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

As a result of processing of the statistical information of indicators of reliability of a cardan shaft it is revealed that the average resource makes 261.95 hours, the standard deviation is equal to 53.2 hours, the coefficient of variation 0.27. The hypothesis of the error of the empirical distribution of resource indicators in comparison with Weibul’s theoretical law is put forward.

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