THE DETERMINATION OF THE MECHANICAL TRANSMISSION MAIN RELIABILITY INDICATORS IN OVERWEIGHT DUMP TRUCKS

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Abstract: This paper determines the most important reliability indicators which characterise the transmission of a Belaz 548A and Belaz 540A dump trucks used in lime pits owned by S.C. Carpatcement Holding S.A Deva. The reliability and non-reliability functions, probability density, malfunction intensity, as well as the average good operation time between two malfunctions are graphically expressed and represented for both types of dump trucks. An accordance test is applied for the validation of theoretical and empirical distributions.

Key words: dump truck, reliability, non-reliability, probabilistic density, malfunction intensity, the average time of good operation between two malfunctions, accordance test

1. GENERAL CONSIDERATIONS

The reliability of overweight vehicles used for the transportation of mineral substances inside open cast mines determined both by the technical conditions of the mine (the configuration and the length of the runway, fuel and lubricants quality, maintenance works modality and periodicity), and by the reliability of their sub-ensembles. One of the most stressed sub-ensembles, where the most of the malfunctions appear is the transmission. That is the reason for which the main objective of this paper is the study of the main reliability indicators of the transmission of the trucks.

The research is based on the machineries inside the quarry owned by SC Carpatcement Holding SA, i.e. Belaz 540A and 548A dump trucks, which have been observed for a period of over a year.

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2. THEORETICAL BASE FOR DETERMINING THE RELIABILITY INDICATORS

Analysis, sorting and process of the data written on the analysis chart of the products is made according to the observed objectives.

The most employed methods for data processing are the graphic representation inside the malfunction schedule or the realisation of tables which will allow the synthesis of information and determining the reliability indicators.

Table data processing allows the construction of relative frequency histograms and of those cumulated, which represent the empirical non-reliability division function, $F^*(t)$. Based on these facts the theoretical distribution of malfunctions law is issued, allowing the determination of reliability indicators. The ratification of this law is made according to several accordance criteria known also as examination tests.

The following steps have been undertaken in order for the dump truck transmission reliability indicators to be determined:

- eliminating the wrong data;
- developing the table with the data filtered ascending;
- class repartition;
- determining the relative and the cumulated random variable frequencies;
- choosing the most appropriate repartition law depending on the empirical repartition;
- estimating the parameters of the chosen repartition law;
- verifying the accordance of the empirical law with the theoretical one;
- determination and graphical representation of reliability indicators.

All of these steps for the establishment of reliability indicators, together with the necessary theoretical basis necessary are comprised within a Matlab developed application. Based on the representation of the relative frequency and on the practical experience the it has come up to the conclusion that out of the repartition laws, the one that best estimates the static repartition is Weibull’s law.

Weibull’s triparametric repartition of distribution is:

$$F(t) = 1 - \exp\left[-\left(\frac{t-\gamma}{\eta}\right)^\beta\right], \quad t \geq \gamma, \beta, \gamma, \eta > 0,$$

where $\beta$, $\gamma$ and $\eta$ are distribution parameters, and $t$ is the random variable, which in this case is expressed by the distance, in km.

For the application of the least square method, a double logarithm is applied to relation (1) and the following notes are made:

$$y = \ln\ln\left(\frac{1}{1 - F(t)}\right);$$
The following equation system is obtained by applying the least square method:

\[
\begin{align*}
na + \beta \sum_{i=1}^{n} \ln(t_i - \gamma) &= \sum_{i=1}^{n} y_i \\
na \sum_{i=1}^{n} \ln(t_i - \gamma) + \beta \sum_{i=1}^{n} \ln^2(t_i - \gamma) &= \sum_{i=1}^{n} y_i \ln(t_i - \gamma) \\
na \sum_{i=1}^{n} \frac{1}{t_i - \gamma} + \beta \sum_{i=1}^{n} \frac{\ln(t_i - \gamma)}{t_i - \gamma} &= \sum_{i=1}^{n} \frac{y_i}{t_i - \gamma}
\end{align*}
\]

(4)

Proceeding with solving of the system the following relations are obtained:

\[
a = \frac{\sum_{i=1}^{n} y_i \sum_{i=1}^{n} \ln^2(t_i - \gamma) - \left[ \sum_{i=1}^{n} y_i \ln(t_i - \gamma) \sum_{i=1}^{n} \ln(t_i - \gamma) \right]^2}{n \sum_{i=1}^{n} \ln^2(t_i - \gamma) - \left[ \sum_{i=1}^{n} \ln(t_i - \gamma) \right]^2}, \quad (5)
\]

\[
\beta = \frac{n \sum_{i=1}^{n} y_i \ln(t_i - \gamma) - \sum_{i=1}^{n} y_i \sum_{i=1}^{n} \ln(t_i - \gamma)}{n \sum_{i=1}^{n} \ln^2(t_i - \gamma) - \left[ \sum_{i=1}^{n} \ln(t_i - \gamma) \right]^2}. \quad (6)
\]

Replacing the values of \(a\) and \(\beta\) into the last relation of (4), \(\gamma\) may be determined, so as \(\partial S / \partial \gamma = 0\), using the following relation:

\[
\frac{\partial g(\gamma)}{\partial \gamma} = \sum_{i=1}^{n} \frac{1}{t_i - \gamma} \left[ \sum_{i=1}^{n} y_i \ln(t_i - \gamma) \sum_{i=1}^{n} \ln(t_i - \gamma) - \sum_{i=1}^{n} y_i \ln(t_i - \gamma) \sum_{i=1}^{n} \ln(t_i - \gamma) \right] + \\
+ \sum_{i=1}^{n} \frac{\ln(t_i - \gamma)}{t_i - \gamma} \left[ n \sum_{i=1}^{n} \ln(t_i - \gamma) - \sum_{i=1}^{n} \ln(t_i - \gamma) \right] - \\
- \sum_{i=1}^{n} \frac{y_i}{t_i - \gamma} \left[ n \sum_{i=1}^{n} \ln^2(t_i - \gamma) - \left( \sum_{i=1}^{n} \ln(t_i - \gamma) \right)^2 \right] = 0. \quad (7)
\]

This equation is frequentative resolved using the interval halving method.

Values are given to \(\gamma\) until:
\[
\frac{\partial g(\gamma_i)}{\partial \gamma} \cdot \frac{\partial g(\gamma_{i+1})}{\partial \gamma} < 0.
\]

(8)

It proceeds with the interval halving until the desired precision is obtained. The value of \( \gamma \) for which the following condition is satisfied \( \left| \frac{\partial g(\gamma_i)}{\partial \gamma} \right| < \) pace, it is the estimation required by the positioning parameters. If 100 iterations are executed without for the above condition to be satisfied, an error pops up and the software closes. If the solutioning process comes up with a value for \( \gamma \) greater than \( t_1 \), this will be detected by the values \( \frac{\partial g(\gamma)}{\partial \gamma} \) which tend to move away from zero, when \( \gamma \) decreases. In this case the software automatically assigns the following value:

\[
\gamma = t_i - 0,001(t_{\text{max}} - t_{\text{min}}).
\]

(9)

If \( \gamma \) becomes negative, without satisfying the condition (8), then the iteration procedure stops, displaying an error message and the positioning parameter is set to zero. \( \gamma \), being determined, all the other parameters may also be determined, parameter \( \beta \) is determined with the relation (6), and parameter \( \eta \) with the following relation

\[
\eta = e^{-\frac{\gamma}{\beta}}.
\]

(10)

The software is also fitted with a sub-software destined to verify the accordance between the theoretical and the empirical distributions using the \( \chi^2 \) test.

3. RESULTS

After loading the software with all the necessary data for the Belaz 548 A dump truck the following values for the triparametric Weibull distribution parameters have been obtained: \( \gamma = 239; \beta = 0.6034403; \eta = 4045.139. \) The probability malfunction density, the representation of which is comprised in Figure 1 is defined by the following relation

\[
f(t) = 14,92 \cdot 10^{-5} \left( \frac{t - 239}{4045.139} \right)^{-0.3965597} \exp \left[ - \left( \frac{t - 239}{4045.139} \right)^{0.6034403} \right].
\]

The non-reliability function, Figure 2, which characterises the transmission of Belaz 548A dump trucks, is:

\[
F(t) = 1 - \exp \left[ - \left( \frac{t - 239}{4045.139} \right)^{0.6034403} \right],
\]

and the reliability function, Figure 2, is expressed through the following relation:
The malfunction rate (intensity), in the case of Weibull’s distribution has been determined with the following relation:

$$R(t) = \exp\left[-\left(\frac{t - 239}{4045.139}\right)^{0.603440}\right].$$

Fig. 1. Probability malfunction density for Belaz 548A

Fig. 2. Reliability and non-reliability functions for Belaz 548A

The malfunction rate (intensity), in the case of Weibull’s distribution has been determined with the following relation:

$$z(t) = \frac{(t - 239)^{0.396559} \cdot 0.603440}{4045.139^{0.603440}}.$$
and it is graphically represented in proportion to the runway, in Figure 3.

As the schedule of probability time density function is powerfully asymmetric, the median of the time until a malfunction has been determined \( t_{\text{med}}(t_{0.5}) \) defined by the equality:

\[
R(t_{\text{med}}) = 0.5,
\]

By resolving the above equation the \( t_{\text{med}} = 2,596.478 \) km has been obtained.

The operation time quintile \( t_\alpha \) represents the period of time where the malfunctioned elements proportion do not surpass the default value \( \alpha \), known as reliable life of a product, where \( \alpha \) is the first class error, respectively the risk of the supplier. As long as the time quintile does not relate to the operation time this may be interpreted as warranty period. The time quintile is defined as the root of the equations \( F(t_\alpha) = \alpha \).

In the case of Belaz 548A dump trucks the first degree error has been accepted to be 0.05. The warranty time has been determined to be the solution of the equation:

\[
F(t_\alpha) = 1 - \exp\left\{-\frac{(t_\alpha - 239)}{4045.139}\right\}^{0.6034403} = 0.05.
\]

By solving the above equation \( t_\alpha = 422 \) km has been obtained.

For the Weibull distribution parameters for Belaz 540A dump truck, the following values have been obtained: \( \gamma = 101; \beta= 0.6399353; \eta=3123.602 \).

The probabilistic malfunction density time is expressed by the relation

\[
f(t) = 2.05 \cdot 10^{-4} \left(\frac{t-101}{3123.602}\right)^{-0.3600647} \exp\left[-\left(\frac{t-101}{3123.602}\right)^{0.6399353}\right].
\]

The malfunction of the transmission of these dump trucks is

\[
F(t) = 1 - \exp\left\{-\frac{(t-101)}{3123.602}\right\}^{0.6399353}.
\]

For the Belaz 540A dump trucks transmission, the resulting formulas for the
reliability function, and the malfunction intensity is:

\[ R(t) = \exp \left( -\frac{t - 101}{3123.602}^{0.6399353} \right); z(t) = \frac{(t - 101)^{0.6399353 - 1}}{3123.602^{0.6399353}}. \]

Figures 4, 5, and 6 graphically represent the variations in proportion to the path of the function density indicators, non-reliability, reliability and malfunction rate.

![Fig. 4. Probability malfunction density for Belaz 540A](image1)

![Fig. 5. Reliability and non-reliability functions for Belaz 540A](image2)
As the operation time probabilistic function density schedule is powerfully asymmetrical, the operation time median until a malfunction has been determined $t_{med}(t_{0.5})$ defined by the equality $R(t_{med}) = 0.5$.

By solving the above equation $t_{med} = 1,863$ km has been obtained. For Belaz 540A dump trucks the first hand error value has been accepted to be $0.05$. The warranty time has been determined to be the solution for the equation:

$$F(t_a) = 1 - \exp\left(-\left[\frac{(t_a - 101)}{3123.602}\right]^{0.6399353}\right) = 0.05.$$

By solving the above equation $t_a = 131$ km is obtained.

4. CONCLUSIONS

The reliability of dump trucks transmission may be studied with the Weibull triparametric distribution, the parameters of which are determined with the help of the software developed in this respect. In case of long used trucks it is appreciated that the most viable for the study of reliability is the Weibull distribution. The software uses the least square method in order to estimate the parameters of the distribution.

The determined values for the parameters of the distribution show that the transmissions of the trucks are getting closer to the end of the normal operation period. For an operation of 4,127,963 km of the Belaz 548A truck 63.2% of them may malfunction, while for the transmission of Belaz 540A trucks the operation has reduced to 2,253.336 km. The starting point for the variation of the reliability function in the transmission of Belaz 548A truck, expressed in operation, is 386.391 km, while for the transmissions of Belaz 540 truck, the variation appears only around 106.391 km.

REFERENCES