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RELIABILITY STUDY OF CAR TIRES

The paper analyzes the primary factors defining the reliability of car tires. Using statistical data, the values of the key indicators of tire reliability have been identified.

Keywords: *car tires, tire reliability, car tire life.*

An automobile is a complex system composed of many elements. Each element contributes to the reliability of the whole system. One of those elements is car tires. While replacing a failed element does not cause significant difficulties, in the process the car goes out of order. That entails a reduction of the vehicle's reliability factors. Individually, car tires are analyzed based on the whole range of reliability factors: fail-free operation, durability, maintainability, storability. In most cases the reliability of tires is evaluated as per totality of the factors. Among the factors defining the reliability of tires are tread wear

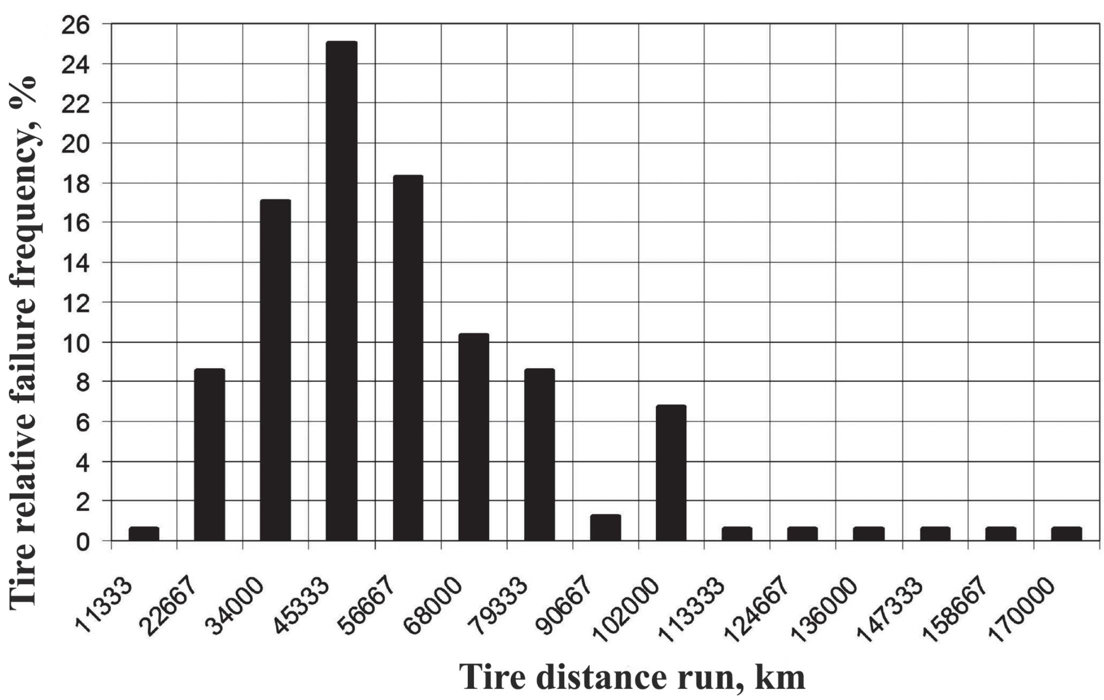

Fig. 1. Bar chart of tire failure frequency distribution depending on the distance run

(down to the minimum allowed size), punctures and cuts, fatigue-related defects of tire carcass or all factors simultaneously. Thus, [1] shows the probability function of dependable operation of truck tires as per the above factors. Examples of distribution of recovered tires taken out of operation based on distance run and identification of expected distance run are presented in [2].

Based on statistical data gathered by tire repair centers, an analysis of car tire reliability has been conducted. We suggest using the following reliability factors: probability of tire dependable operation, probability of failure, failure density, failure rate, gamma-percentile tire life, distribution law of tire failure depending on distance run. Such reliability factors as maintainability and storability of car tires are not considered in this paper. The tire life information gathered reflects the fact of tire decommissioning while repair operations are not included in the statistical data. As provided in relevant regulatory documents, the manufacturer of car tires guarantees their storability within 5 years from the date of manufacture.

Based on the input data, the tires were grouped according to the distance run with the following parameters: number of partition intervals m = 15; length of intervals Δt = 11334 km. As a result, a bar chart of tire failure frequency distribution depending on the distance run was constructed (Fig. 1).

As per [3], the probability of dependable operation is the quantitative measure of non-occurrence of a single failure under certain operational conditions within a given time interval or within a given operation time and is determined from the formula:

$$P(t) = \frac{N - n(t)}{N}, \tag{1}$$

where N is the number of tested units; n(t) is the number of units that failed within the time t.

The probability of failure is the quantitative measure of at least one failure occurring under certain operational conditions within a given time interval. Failure and dependable operation are incompatible and opposite events. Therefore, the probability of failure is determined from the formula [3]:

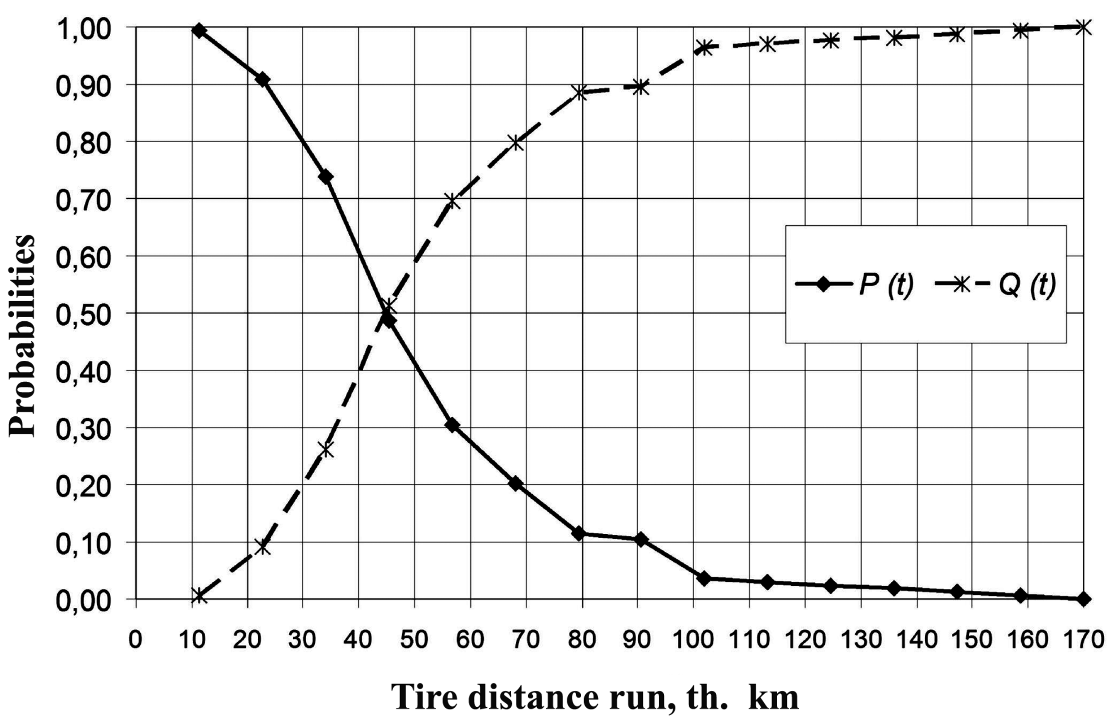

Fig. 2. Integral functions of dependable operation P(t) and failures Q(t)

$$Q(t) = 1 - P(t). \tag{2}$$

Calculated values as per formulas (1) and (2) are represented in the form of graphs in Fig. 2.

The tire's gamma-percentile life can be determined by the graph. It is defined as the total operation time during which a unit does not reach a certain condition with a probability expressed as a percentage [4]. Then a 90% gamma-percentile life will amount to 23000 km of distance run which corresponds to the probability of tire dependable operation of 0,9. Furthermore, integral function analysis (Fig. 2) shows that a 50% probability of tire dependable operation is 45000 km of distance run.

The failure density according to statistical data is the relation of the number of failed elements per unit time to the initial number of operable (tested) ones and is determined from the formula [3]:

$$f(t) = \frac{n(\Delta t)}{N \cdot \Delta t}, \tag{3}$$

where n(Δt) is the number of failed elements within the time interval from (t – Δt)/2 to (t + Δt)/2.

The failure rate according to statistical data is the relation of the number of failed units per unit time to the average number of units operating dependably within a given time period [3]:

$$\lambda(t) = \frac{n(\Delta t)}{N_{\varphi} \cdot \Delta t}, \tag{4}$$

where N_{cp} is the average number of operable units within the time interval Δt.

The values of failure density and failure rate are identical in order and degree, and therefore can be expressed within the same coordinate space. Calculation data as per formulas (3) and (4) are represented in Fig. 3.

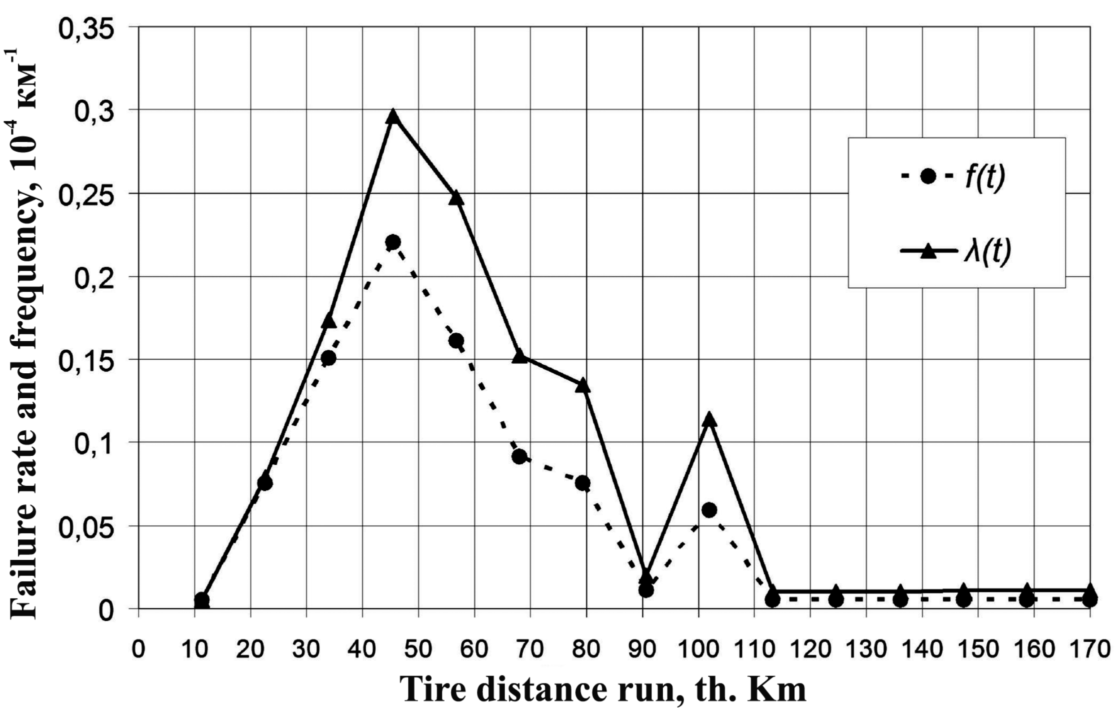

Fig. 3. Diagram of dependence of car tire failure density f(t) and rate λ(t) from the distance run

Average time (of operation) is calculated according to formula [3]:

$$T_1 \approx \frac{\sum_{i=1}^{m} n_i \cdot t_{cpi}}{N}, \tag{5}$$

where t_{cpi} is determined according to the formula: $t_{cpi} = (t_{i-1} + t_i)/2$.
where t_{i-1} is the time of the beginning of the *i*-interval; t_i is the time of the end of the *i*-interval.

Calculations according to formula (5) show that the average fault-less distance run by a tire is T_1 = 50790 km.

In general, the results of tire failure monitoring (Fig. 1) may follow a certain theoretical law of distribution. The verification of the theoretical distribution of monitoring results is performed using matching criteria χ^2. The identified theoretical distribution is confirmed if the following condition is true [5]:

$$\chi^2 < \chi^2_\alpha, \tag{6}$$

where χ^2 is the calculated parameter value; χ^2_α is the theoretical parameter value.

For a 10-percent significance and the number of the degrees of freedom equal to 6, the tabulated point χ^2_α = 10.645 [5]. The selection of theoretical distributions has provided the following results:

1. Normal distribution is χ^2 = 39.16.
2. Gamma distribution is χ^2 = 14.97.
3. Logarithmically normal distribution is χ^2 = 9.26.

The condition (6) is true only if the logarithmically normal distribution is 9.26<10.645.

Therefore, in order to identify the reliability of tires, the logarithmically normal distribution law is applied. Fig. 4 shows the theoretical distribution and experimental data curves.

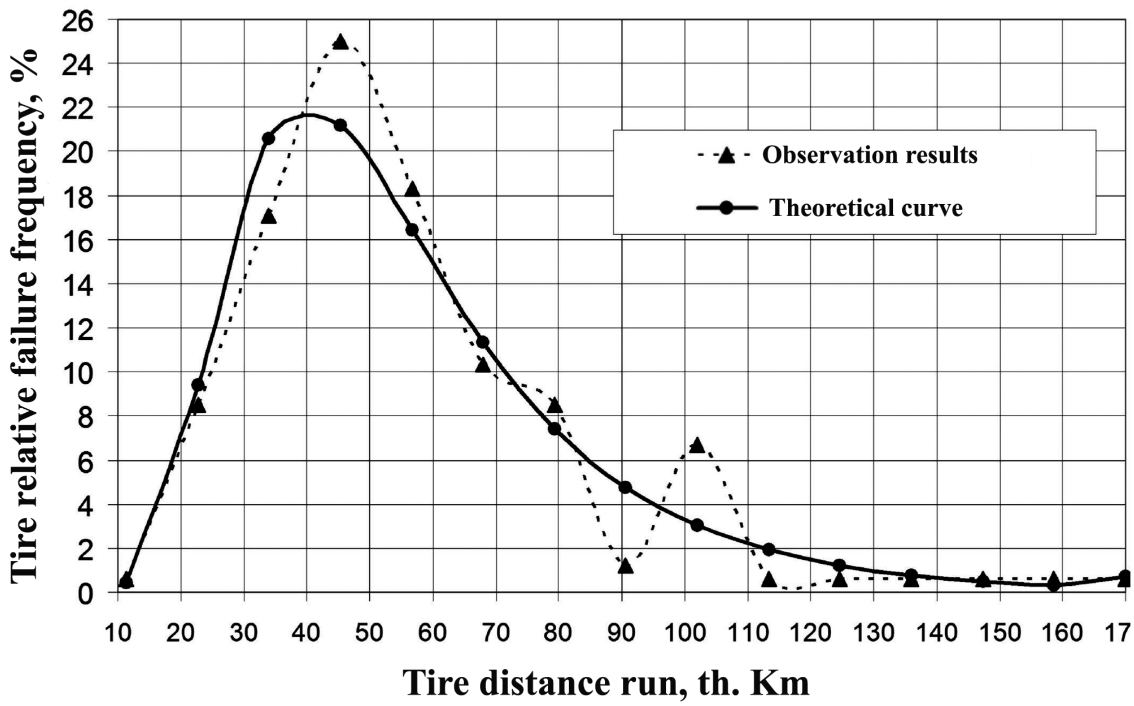

Fig. 4. Car tire failure theoretical distribution and experimental data curves

The conformity of experimental data with the logarithmically normal distribution law means that a random value (tire reliable operation) depends on a large number of unrelated factors [6]. In fact, a number of factors affect the reliability of car tires: quality of tires, condition of the road, car speed, driver's skill, tire pressure, wheel alignment, etc.

Based on the presented data, the following conclusions can be made. Statistical data of car tire operation match the logarithmically normal random distribution law. Furthermore, the theoretical operation time is somewhat lower than the actual one. As shown in the chart (Fig. 1), most of the tires (about 42%) fail at the 45-56 thousand kilometers of distance run. However, according to the theoretical law, most of the tires (41.5%) fail within the 34-45 thousand kilometer interval (Fig. 4). Then, the theoretical probability of reliable operation is 0.5-0.3, while the experimental probability of reliable operation is 0.74-0.5. The 10-percent probability of tire failure occurs after 23 thousand kilometers run. At the same time, the average reliable operation is 50790 kilometers. Maximum tire distance run reaches 170000 kilometers. Only 12% of tires reach distances run over 90000 kilometers, and their failure probability is 0.9. However, this shows a potential for increased car tire reliability by means of improvement of the quality of the factors that define their life.

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