Assessment of the wear resistance of tyre treads on the basis of bench tests using a binomial series

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Tyre durability is determined largely by tread wear. Actual tyre life in terms of tread wear is assessed by service tests. However, to obtain the required accuracy of tyre wear data under service conditions, it is necessary to test a fairly large number (200–500) of tyres of each batch [1]. A full report on tyre life can be given only after practically all test tyres have failed. Therefore, service tests are drawn out and normally last at least 2 years, which makes it difficult to use the test results for improving the design or manufacturing technology of future tyres.

Accelerated road tests to determine tread wear have been widely used. These are conducted under intensive driving conditions with ballast and a daily average run of 600–800 km. Under these conditions, the test time to complete tyre wear is considerably reduced. Accelerated road tests of tyres are comparative, and several tyre modifications are tested in parallel. To eliminate any influence that the time for which a tyre is in a particular position on the vehicle may have on the wear of the tyre set, it is necessary for each tyre to travel the same number of kilometres in each position. On the basis of this requirement, the total run of tests amounts to 40 000–50 000 km for lorry tyres and 20 000–25 000 km for car tyres. Since tyre wear depends on ambient temperature [2] and the state of the road surface [3], these tests are organised so that their complete cycle extends over one summer season – from April to October. As a result, with double-shift work and average vehicle speeds, the total test time is 2–3 months for car tyres and 4 months for lorry tyres.

Bench tests of tyres to determine tread wear are more productive than road tests and enable the influence of the main service factors and design parameters on the wear resistance of the tread to be modelled with sufficient accuracy [4].

In the zone of contact of the tyre with the road surface, tangential $P_x$, lateral $P_y$, and vertical $P_z$ forces are active. The magnitude of these forces is influenced by many service factors (road factors – the road category, the terrain of the locality, the state of the road surface, the traffic conditions, the climatic conditions) and also by design parameters of the vehicles. In bench tests it is possible to model the influence of each of these factors on the forces acting in the zone of contact of the tyre with the road, which determine the wear resistance of the tread.

There exist different dependences of the wear resistance of tyre treads on the action of the lateral and longitudinal forces at the point of contact, for example the exponential dependence [5]

$$ J = J_0 + B_1 \left( \frac{P_x}{P_z} \right)^n + B_2 \left( \frac{P_y}{P_z} \right)^m + B_3 \left( \frac{P_x P_y}{P_z^2} \right)^k \quad (1) $$

where $J_0$ is the intensity of tread wear of a driven wheel, $B_1$ is a coefficient characterising the tyre design, and $n$, $m$, and $k$ are the degrees of influence of the given parameters on tyre wear.

Physically, the ratios $\mu_x = P_x/P_z$ and $\mu_y = P_y/P_z$ are the friction coefficients of the tyre with the road or with the bench surface. Depending on the loading regime, the coefficients of rolling or sliding are used in motor vehicle terminology. These coefficients are always less than unity, which makes it possible to propose the following equation for estimating the wear resistance of tyres as a function of the forces acting in the contact zone:

$$ J = J_0 \left( 1 + \frac{P_x}{P_z} \right)^n \left( 1 + \frac{P_y}{P_z} \right)^m \quad (2) $$
Expansion into a Maclaren series of a binomial series having a radius of convergence of less than unity has the form

\[(1 + x)^k = 1 + kx + \frac{(k(k - 1))}{2}x^2 + \cdots \tag{3}\]

By multiplying the second and third components of formula (2), we obtain a dependence similar to formula (1).

We will show, for a specific example, the legitimacy of the proposed formula. The wear resistance of the tyre tread was determined by the STP-IA procedure on an adapted IPZ-4MI bench installed at the Volzhskii Tyre Factory. Three tyre sets were tested, the tangential force \(P_x\) was varied on three levels, the lateral force \(P_y\) was varied on five levels, and the normal load \(P_z\) was constant and amounted to 4.1 kN (Table 1).

The main task of statistical processing of the experimental results is to determine the values of exponents \(m\) and \(n\) in equation (2).

We will linearise equation (2):

\[\ln J = \ln J_0 + n\ln(1 + \mu_x) + m\ln(1 + \mu_y)\]

Assuming that \(\ln J = z\), \(\ln(1 + \mu_x) = x\), and \(\ln(1 + \mu_y) = y\), we obtain a system of linear equations for determining exponents \(m\) and \(n\), which depend on a large number of factors, both service and design factors.

After statistical processing of the data given in Table 1, we obtain the following regression equation:

\[J = 15.68(1 + P_x/P_y)^{4.1}(1 + P_y/P_z)^{11.5}\]

The obtained exponent \(n = 4.1\), \(n\) characterising the degree of influence of the longitudinal force \(P_x\), is considerably lower in value than the exponent \(m = 11.5\), \(m\) being the degree of influence of the lateral force.

Calculation of the total and residual variances and the coefficient of agreement (Fisher’s variance ratio) showed that the experimental value of Fisher’s variance ratio (\(F = 6.9\)) is greater than the tabular value.

Thus, on the basis of processing experimental bench-test data, an equation has been proposed that makes it possible, with sufficient accuracy, to describe the dependence of the intensity of tread wear on the forces acting at the point of contact. Similar results after statistical processing of test-bench data were obtained for other tyre sets, both lorry and car tyres.

REFERENCES


5. V. A. Gudkov et al., Kauch. i Rezina, No. 6, 1991, p. 32.

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Table 1. Effect of the torque and tangential and lateral forces on the intensity of tread wear of model MI-166 tyres

| \(M_t\), N·m | \(P_y\), N | Wear intensity, g/100 km, at different values of \(P_y\) |
|---|---|---|---|---|---|---|
| | | \(P_y = 0\) N | \(P_y = 310\) N | \(P_y = 610\) N | \(P_y = 920\) N | \(P_y = 1230\) N |
| 0 | 0 | 2.8 | 3.1 | 3.8 | 16 | 60.0 |
| 150 | 0.5 | 3.0 | 4.0 | 7.2 | 20 | 65.0 |
| 300 | 1.0 | 6.0 | 8.0 | 16.6 | 40 | 98.5 |