13th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2009, Hammamet, Tunisia, 16-21 October, 2009

INFLUENCE OF DAMAGE HYPOTHESES ON RELIABILITY EVALUATION OF VEHICLE TRANSMISSION ELEMENTS

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ABSTRACT
In order to upgrade the vehicle transmission elements in terms of reducing their size and weight and simultaneous achieving required level of reliability the contemporary design of these elements is based on real stochastic nature of working and permissible stresses as design basic values. Therefore, reliability evaluation of the vehicle transmission elements is made on the base of probability where working stresses are lower than permissible ones. In that respect, this paper deals with reliability evaluation of vehicle transmission elements, highlighting of the driving shafts, and influence of different damage hypotheses on results of the evaluation.
Keywords: damage hypotheses, reliability evaluation, vehicle transmission, driving shaft

1. INTRODUCTION
Probabilistic approach to design of vehicle transmission is related to the solution of number of complex problems. The major problem is determination of variability, values and laws on distribution of working and permissible stresses in relation to road conditions. To determine the form of distribution and intervals of dispersion of working stresses directly, we may use experimental examinations of prototype in road conditions alike exploitative or indirectly on the base of previous experimental examinations of transmission of similar vehicles in quiet similar road conditions. Also to determine form and intervals of dispersion of permissible stresses directly, we may use laboratory examinations or indirectly by applying damage hypotheses. Surpassing these problems enables to evaluate the reliability of vehicle transmission elements during its design, on a base of the attained distributions of working and permissible stresses, what leads to vehicle transmission elements that should demonstrate highest results in exploitative conditions.

2. METHOD
2.1 Determination of distribution of working stresses
Reliability evaluation of vehicle transmission elements is based on the results of the examination of transmission working loads of prototype vehicle in exploitative conditions. It is a truck with a motor power P=147 kW at a number of revolutions of n=2200 o/min, with double driving bridges with semi axial differential mounted between, that enables equal distribution of a torque at both driving bridges. Examination of torque change is realized under different road conditions according to categorization of road conditions given in the table 1.

Table 1. Categorization of road conditions (Faculty of Mechanical Engineering in Belgrade)

Category	Description	Average participation [%]
G	Urban condition of traffic, asphalt surface, average slope	5
I	Highways, small slopes, slight curves	15
II	Roads of average quality, average slopes, sharp curves	50

III	Macadam roads, mid slopes, slight curves	25
IV	Roads of law quality, rough slopes, sharp curves	5

The measurement of the torque is made on cardan shaft and achieved results are given in the figure 1 [1]. Period of operation and average velocity at a particular transmission gear are also observed and the achieved results are given at the figures 2 and 3 [1]. Reliability evaluation is made for driving shaft as one of the essential elements of vehicle transmission whereof the distribution of working stresses τ is formed for road conditions with chosen participation of particular categories of road conditions.

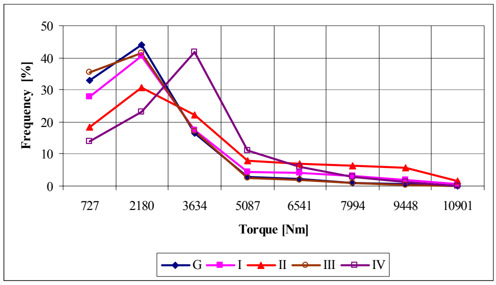

Figure 1. Distributions of driving shaft torque

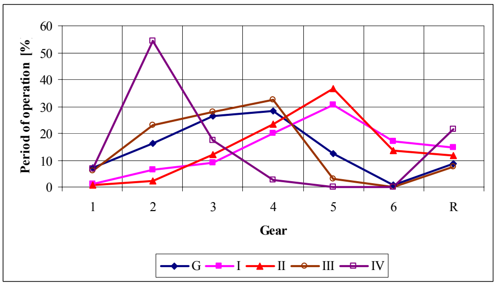

Figure 2. Distributions of period of operation at each transmission gear

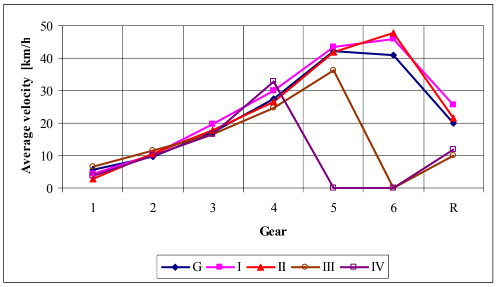

Figure 3. Distributions of average velocity at each transmission gear

Weibul's distribution is adopted for distribution of working stresses [1]:

$$f(\tau)=\frac{\beta}{\eta}\cdot\tau^{\beta-1}\cdot e^{-\left(\frac{\tau}{\eta}\right)^{\beta}} \tag{1}$$

, in which β and η are distribution parameters.

2.2. Determination of distribution of permissible stresses

Gaussian distribution is adopted for distribution of permissible stresses [1]:

$$f(\tau_N)=\frac{1}{\sigma\cdot\sqrt{2\cdot\pi}}\cdot e^{-\frac{1}{2}\left(\frac{\tau_N-\bar{\tau}_N}{\sigma}\right)^2} \tag{2}$$

, in which τ_N is endurance limit of driving shaft material and σ and $\bar{\tau}_N$ are distribution parameters, which are determined by the following equations:

$$\bar{\tau}_N=\frac{\tau_{N,\max}+\tau_{N,\min}}{2}\quad,\quad\sigma=\frac{\tau_{N,\max}-\tau_{N,\min}}{6} \tag{3}$$

, in which $\tau_{N,min}$ and $\tau_{N,max}$ are the limits of interval of endurance limit dispersion. Mechanical properties of driving shaft material, steel Č4830 are given in Table 2.

Table 2. Mechanical properties of steel Č4830 [7]

Endurance limit under repeated cyclic loading $\tau_{D(0)}$ [N/mm^2]	370÷550
Endurance limit under reversed cyclic loading $\tau_{D(-1)}$ [N/mm^2]	260÷330
Exponent of Wohler's curve m [1]	3.5
Base number of cycles N_D [1]	$6\cdot10^6$

Determination of the limits of interval of endurance limit dispersion and number of cycles up to failure N_R of driving shaft is based on the following damage hypotheses:

Palmgren-Miner [5,6]

$$N_R = \frac{N_1}{\sum_{i=1}^{j} f_i \cdot \left(\frac{\tau_i}{\tau_1}\right)^m} \tag{4}$$

Corten-Dolan [4]

$$N_R = \frac{N_1}{\sum_{i=1}^{j} f_i \cdot \left(\frac{\tau_i}{\tau_1}\right)^{g\cdot m}} \; , \quad \begin{matrix} g = 0.7 \div 1.0 & za & \frac{\tau_T}{\tau_N} = 1.2 \div 1.5 \\ g = 1.0 \div 1.6 & za & \frac{\tau_T}{\tau_N} = 2.0 \div 3.0 \end{matrix} \tag{5}$$

Haibach [3]

$$N_R = \frac{N_1}{\sum_{i=1}^{j} f_i \cdot \left(\frac{\tau_i}{\tau_1}\right)^m + \sum_{i=j+1}^{k} f_i \cdot \left(\frac{\tau_i}{\tau_1}\right)^{2\cdot m-1}} \tag{6}$$

Serensen-Kogaev [2]

$$N_R = a_r \cdot \frac{N_1}{\sum_{i=1}^{j} f_i \cdot \left(\frac{\tau_i}{\tau_1}\right)^m} \; , \; a_r = \frac{\frac{\tau_1}{\tau_N} \cdot \sum_{i=1}^{j} f_i \cdot \left(\frac{\tau_i}{\tau_N}\right) - 0.5}{\frac{\tau_1}{\tau_N} - 0.5} \; \text{za } a_r \geq 0.2 \tag{7}$$

, in which N_1 is number of cycles up to failure under cyclic loading of magnitude which is equal to the peak value of working load, τ_1 is the peak value of working stresses and f_i is frequency of i-th working stress τ_i. Endurance limit of driving shaft τ_{DM} is determined according to the following equation [1]:

$$\tau_{DM} = \frac{\tau_{D(-1)} \cdot \xi_\tau \cdot \xi_1}{k_\tau} + \frac{\tau_{D(0)} - \tau_{D(-1)}}{0.5 \cdot \tau_{D(0)}} \cdot \bar{\tau} \tag{8}$$

, wherein ξ_τ=(0.6÷1)=1 is influence factor of difference between the size of the test tube and driving shaft, k_τ =(1.4÷1.5)=1.5 is stress concentration coefficient and ξ_1=(1÷1.25)=1 is surface condition factor, $\bar{\tau}$ is an arithmetic mean of distribution of working stresses. Total number of cycles N during service life of driving shaft is determined after average number of cycles per 1 km of roads and participation of particular categories of road conditions in service life of driving shaft. Average number of cycles per 1 km of road with asphalt surface N_c^a is determined according to equation [1]:

$$N_c^a = \sum_{i=1}^{k} t_i \cdot \frac{3600 \cdot n_i}{v_i} \tag{9}$$

, in which t_i is relative participation of i-th transmission gear and n_i is individual transmission frequency of i-th transmission gear, which is given in Table 3.

Table 3. Individual transmission system frequency [1]

Transmission gear	I	II	III	IV	V	V	R.g.
n [Hz]	0.4	1.5	2.3	4.0	5.3	6.7	8.0

Average number of cycles per 1 km of macadam and land road N_c^z is determined according to the following equation [1]:

$$N_c^z = \frac{3600}{2 \cdot \pi \cdot \bar{v}} \sqrt{\frac{C}{m_v}} \tag{10}$$

, in which C is stiffness of the suspension system and m_v is suspended mass reduced to the driving wheels (C/m_v=168 kN/mt [1]).

2.3. Reliability evaluation

Reliability evaluation is made after determination of distributions of working and permissible stresses according to the following equation [1]:

$$R = 1 - \int_{\tau_{N,\min}}^{\tau_{\max}} f(\tau_N) \cdot \left[\int_{\tau_N}^{\tau_{\max}} f(\tau) \cdot d\tau \right] \cdot d\tau_N \tag{11}$$

3. RESULTS

Reliability evaluation is made for road conditions with participation of particular categories of road conditions given in Table 4.

Table 4. Chosen road conditions

Road conditions	1	2	3	4
G-I-II-III-IV	5-15-50-25-5	5-15-70-5-5	5-5-5-70-15	5-5-5-15-70

Service life of driving shaft is supposed to be 300,000 km. Limits of interval of endurance limit dispersion $\tau_{N,min}$ and $\tau_{N,max}$ are determined based on the following condition: $N_R \geq N$ in which N is total number of cycles during service life of driving shaft. Typical dependences of reliability versus driving shaft diameter for chosen road conditions and different damage hypothesis are shown in the figure 4.

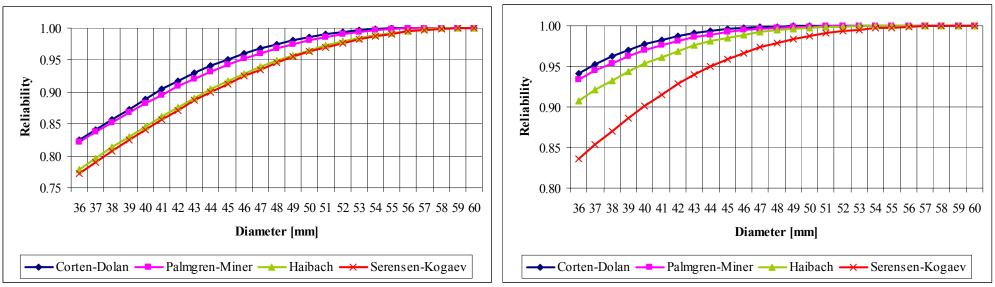

Figure 4. Dependences of reliabilty versus driving shaft diameter for road conditions no.1 and no.3

4. CONCLUSION

Very simillar results of reliability evaluation are obtained for each chosen road conditions when Palmgren-Miner's and Corten-Dolan's damage hypotheses are used. In case of using Haibach's and Serensen-Kogaev's damage hypotheses results of reliability evaluation are also very simillar except for road conditions with higher participation of categories III and IV which causes significant difference in results of reliability evaluation. Generally speaking reliability evaluation in case of using Palmgren-Miner's and Corten-Dolan's damage hypotheses leads to higher values of driving shaft reliability for each road conditions than reliability evaluation in case of using Haibach's and Serensen-Kogaev's damage hypotheses. Comparison of results of reliability evaluation in case of using Haibach's and Serensen-Kogaev's damage hypotheses showes higher values of driving shaft reliability for road conditions with higher participation of categories III and IV in case of using Haibach's hypothesis.Achieved dependences of reliability versus driving shaft diameter for chosen road conditions and different damage hypotheses could be used in methods of probabilistic design for a variety of different road conditions. This results show that it is feasible to achieve considerable reduction of driving shaft diameter retaining high level of reliability.

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