12^{th} International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2008, Istanbul, Turkey, 26-30 August, 2008

INFLUENCE OF ROAD CONDITIONS ON RELIABILITY OF VEHICLE TRANSMISSION

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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 critical stresses as design basic values. Consequently, working and critical stresses are considered as random variables with distribution at appropriate intervals of dispersion where different values of working and critical stresses find different appearance probabilities. Therefore, reliability evaluation of the vehicle transmission elements is made on the base of probability where working stresses are lower than critical ones. In that respect, this paper deals with the influence of road conditions on reliability of the vehicle transmission elements highlighting of the driving shafts with different diameters.

Keywords: road conditions, reliability, vehicle transmission

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 critical stresses in relation to road conditions. To achieve 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 achieve form and intervals of dispersion of critical stresses directly, we may use laboratory examinations or indirectly by applying cumulative damage hypothesis.

By surpassing these problems it is enabled to evaluate the reliability of vehicle transmission elements during its design, what leads to vehicle transmission elements of optimal dimensions 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 FAP prototype vehicle in exploitative conditions [4]. 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. The efficiency of differential is ν=0.95 and transmission ratio is i=6.8.

Examination of torque change is realized under different road conditions according to the following categorization: G-Urban condition of traffic, asphalt surface, average slope; I- Highways, small slopes, slight curves; II-Roads of average quality, average slopes, sharp curves; III-Macadam roads, mid slopes, slight curves; IV-Roads of law quality, rough slopes, sharp curves. The measurement of the torque is made on cardan shaft and achieved results are given in the table 1. At the same time, period of operation and average velocity at a particular transmission gear are also observed and the achieved results are given at the table 2.

Table 1. Experimental results of torque measurement

Cardan shaft M_k [Nm]	Driving shaft M_p [Nm]	Frequency [%]				
		G	I	II	III	IV
450	726.8	33.00	28.00	18.30	35.39	14.00
1350	2180.3	44.00	40.50	30.84	41.50	23.00
2250	3633.8	16.37	17.49	22.28	17.20	41.69
3150	5087.3	3.00	4.38	7.95	2.57	11.00
4050	6540.8	2.06	4.00	7.00	1.87	6.00
4950	7994.3	1.00	3.15	6.40	0.95	3.00
5850	9447.8	0.48	2.00	5.74	0.45	1.19
6750	10901.3	0.09	0.48	1.51	0.07	0.12

Table 2. Experimental results of vehicle average velocity measurement

Transmission gear	G		I		II		III		IV	
	% t	v [km/h]	% t	v [km/h]	% t	v [km/h]	% t	v [km/h]	% t	v [km/h]
1	7.21	5.57	1.31	4.43	0.79	2.70	5.95	6.52	6.95	3.71
2	16.18	9.66	6.48	10.44	2.10	10.62	23.11	11.59	54.52	9.95
3	26.30	17.21	9.13	19.81	11.99	17.71	27.81	16.63	17.19	16.51
4	28.45	27.45	20.03	30.09	23.58	26.68	32.45	24.62	2.62	32.73
5	12.39	42.33	30.62	43.38	36.53	42.01	3.01	36.25	-	-
6	0.61	40.90	16.99	45.82	13.49	47.95	-	-	-	-
Reverse gear	8.86	19.90	14.83	25.56	11.51	21.56	7.67	10.01	21.43	11.78
$\bar{v}$ [km/h]	-	21.56	-	35.52	-	32.94	-	17.53	-	11.65

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. Weibul's distribution is adopted for distribution of working stresses [2]:

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

, in which β and η are distribution parameters.

2.2 Determination of distribution of critical stresses

Gaussian distribution is adopted for distribution of critical stresses [2]:

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

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

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

, in which $\tau_{N,min}$ and $\tau_{N,max}$ are the limits of interval of endurance limit dispersion. Mechanical properties of steel Č4830, that driving shaft is manufactured of, are given in table 3.

Table 3. Mechanical properties of steel Č4830 [6]

Endurance limit under one-way alternate load $\tau_{D(0)}$ [N/mm^2]	370÷550
Endurance limit under periodic alternate load $\tau_{D(-1)}$ [N/mm^2]	260÷330
Exponent of Wohler's curve m [5]	3.5
Base number of cycles N_D [5]	$6 \cdot 10^6$

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 Haibach's cumulative damage hypothesis [2]:

$$N_R = \frac{N_1}{\sum_{i=1}^{j} f_i \cdot \left(\frac{\tau_i}{\tau_1}\right)^m + \sum_{i=j+1}^{k} f_i \cdot \left(\frac{\tau_i}{\tau_1}\right)^{2\cdot m-1}} \tag{4}$$

, in which N_1 is number of cycles up to failure under periodic alternate load 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. Endurance limit under periodic alternate load $\tau_{D(-1)M}$ of driving shaft is determined according to the following equation [5]:

$$\tau_{D(-1)M} = \frac{\tau_{D(-1)} \cdot \xi_\tau \cdot \xi_1}{k_\tau} \tag{5}$$

, 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. Endurance limit of driving shaft τ_{DM} is determined according to the following equation [5]:

$$\tau_{DM} = \tau_{D(-1)M} + \frac{\tau_{D(0)} - \tau_{D(-1)}}{0.5 \cdot \tau_{D(0)}} \cdot \bar{\tau} \tag{6}$$

, in which $\bar{\tau}$ 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 the following equation [5]:

$$N_c^a = \sum_{i=1}^{k} t_i \cdot \frac{3600 \cdot n_i}{v_i} \tag{7}$$

, 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 4.

Table 4. Individual transmission system frequency [5]

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 [5]:

$$N_c^z = \frac{3600}{2 \cdot \pi \cdot \bar{v}} \sqrt{\frac{C}{m_v}} \tag{8}$$

, 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).

2.3 Reliability evaluation

Reliability evaluation is made after determination of distributions of working and critical stresses according to the following equation [3]:

$$R = 1 - \int_{\tau_{N,\min}}^{\tau_{\max}} f(\tau_N) \cdot \left[\int_{\tau_N}^{\tau_{\max}} f(\tau) \cdot d\tau\right] \cdot d\tau_N \tag{9}.$$

3. RESULTS

Reliability evaluation is made for different road conditions with participation of particular categories of road conditions given in table 5. This evaluation is made for different driving shaft diameters smaller than driving shaft diameter where starts overlapping of working and critical stresses d_o.

Table 5. List of chosen road conditions

Road conditions	1 (average participation)	2	3	4	5
G-I-II-III-IV	5-15-50-25-5	5-15-70-5-5	5-55-30-5-5	5-5-5-70-15	5-5-5-15-70

Service life of driving shaft is to run 300,000 km and total number of cycles N during service life of driving shaft determined for each chosen road condition is given in table 6. Limits of interval of endurance limit dispersion $\tau_{N,min}$ and $\tau_{N,max}$ are determined based on the following condition: $N_R \geq N$ and value of driving shaft diameter d_o, which is also given in table 6, is determined.

Table 6. Number of cycles during service life and driving shaft diameter d_o

Road conditions	1	2	3	4	5
N [10^6·cycles]	97.7	142.8	140.4	103.9	133.9
d_o [mm]	60	62	61	55	57

Afterwards parameters of distributions of working and critical stresses are determined and reliability evaluation is made based on these distributions. Obtained curves of dependence of reliability and driving shaft diameter for chosen road conditions are shown in figure 1.

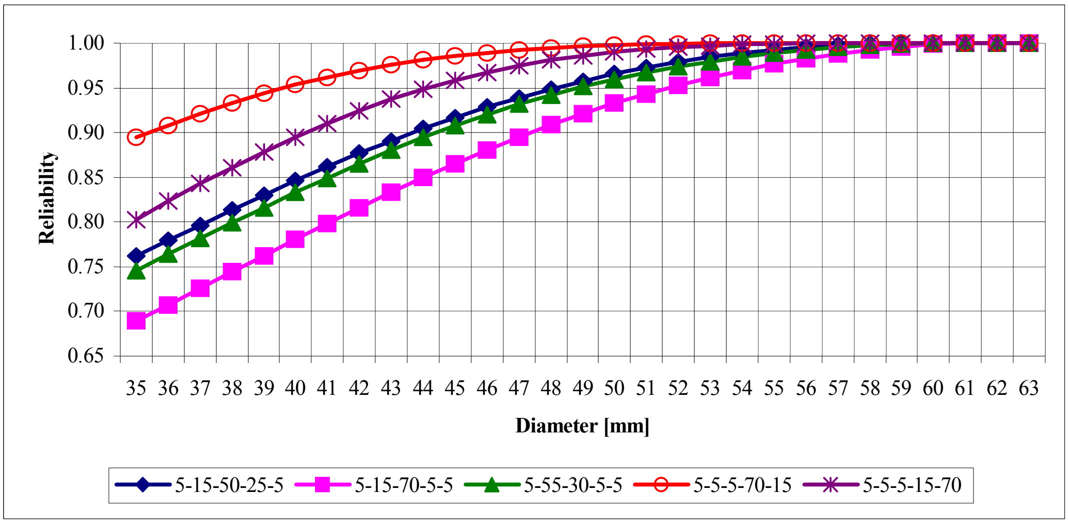

Figure 1. Curves of dependence of reliabilty and driving shaft diameter

4. CONCLUSION

Obtained diagram with curves of dependence of reliability and driving shaft diameter for different road conditions could be used in methods of probabilistic design for a variety of very different road conditions. This diagram shows that it is feasible to achieve considerable reduction of driving shaft diameter retaining high level of reliability. In that respect, obviously it is feasible to carry out optimal design of vehicle transmission elements retaining at the same time, reliability on a satisfactory level what altogether improves the quality of transmission.

5. REFERENCES

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