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RESEARCH ARTICLE

Determination of Load and Load Capacity Based On Desired Reliability

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Abstract

Design for reliability, a partial approach that allows determination of design parameters based on pre-defined level of reliability. That means defining reliability in a specific way which is suitable for this purpose. Reliability of design structure and elementary reliability of design components are used as a functional requirement of automotive gearbox (in relation with service life and service conditions) and also as a design constraint in analytic relations. In these circumstances, carrying capacity as a functional requirement is related to service conditions and service regime. This paper presents the results of load spectrum for representative operating conditions of the gearbox, which served as the basis for design parameters determination. The experimental results of the probability of destruction of the gearbox components, as well as processing of the probability of working conditions and as components of reliability for design, are some of the methods used in this paper. On the basis of the developed model the software for the structural optimization has been made.

INTRODUCTION

Design for reliability is one of the partial approaches in the engineering design of components and technical systems and the whole of their structure. This is one of the wider systems of partial approaches known as Design for X, which includes design for manufacturing, Design for Cost, Design for vibration and noise and so on. Functional requirements of design structures, for instance, carrying (load) capacity, reliability, service life etc. are strongly related to service conditions that are, as a rule, random and very often uncertain. The aim of this approach lead to the optimal level of each of these properties of technical systems separately, variation, interrelating or optimization of design parameters. The basic idea is to apply a set of methods in Engineering Design to develop methodology for carrying capacity identification concerning service conditions. An automotive gearbox has been taken for a case study, because it represents the design structure with very variable service conditions. To achieve this aim, different methods and approaches were taken into account such as robust design [6], [13], [2], axiomatic design [14],[15], property-based design, design for X [4], [7], [9], [1] and investigations in the field of automotive gearboxes[12], [3], [8], [10], [11], gears [16]-[18] etc. Work is also continuing studies that were presented in the paper [10] that includes reliability model of gear box and paper [8] who related to the specific way of defining the reliability of gear pairs and bearings in the gearbox. Analysis of possible failure of components of gear box preceded the definition of these models. They conclude that the failure of tooth flank gear, pitting in bearings, seals wear, difficulty in synchronic couplings and mechanisms for inclusion, the main causes of failure gearboxes. Potential failures of tooth flanks of gears and bearings are essential for caring capacity. Failure of flank tooth gear depends on the material of the gears and heat treatment, processed in the work [5].

Analisys of The Driving Conditions

Vehicles in which this type of gear (trucks, bus, etc...) is installed exploit in the diverse and changing conditions. The same vehicle can be exploited under favorable or unfavorable conditions, when it comes to quality of roads, terrain, vehicle capacity utilization, quality of drivers handling and so on. These conditions vary from vehicle to vehicle, and change during life of the vehicle. Representative sample of the exploration service conditions is necessary that would be relevant for defining the design parameters or load design solution which is developed using empirical experience. In this research it used the following approach. We analyzed the conditions of exploitation depending on the terrain, the quality (level) of the road network and capacity utilization. We formed spectra participation of each travel speed along with the size of torque at output shaft gear. Example of the results of this analysis for a ride and exploitation in extremely difficult conditions is given in Figure 1. Based on this set of views consisting of a variety conditions the representative shown in Figure 2, is made with numerical values given in Table 1 Representativeness was obtained by the adopted transmission will be exploited with 30% in the driving conditions in mountainous terrain, 40% for plain terrain and driving on the freeway 30%.
The representative sample shows no significant differences in the use of gears, except first and seventh speeds that are used exceptional. This will affect the election results design parameters of each gear. This means that they will be similar to each other. Since the real exploitation does not follow a representative sample rather than to the individual one that is used to obtain representative, the damage components gear in operation will carry out by the component spectra. Upon completion of work life, or at the end of the work life for an operating conditions will be damaged some of the component and for the other conditions other components will be damaged. Overall reliability, according to the participation speed will be close to the reliability of most damaged components.

Table 1. The participation speeds and the output torque for representative operating conditions and maximal output torques measured in service conditions

Transmissions gear	Speed participation in %	Output torque in Nm	Maximal output torque $T_{outp\text{-}max}$ in Nm
I	1,16	684	4824
II	23,33	645	4630
III	22,1	596	1987
IV	19,27	566	820
V	18,27	584	710
VI	15,67	686	550
R	0,2	880	4900

The second part of the identification of the gearbox exploitation conditions is measurement of the output torque on the Cardan shaft, which is connected to the output of gearbox shaft, for each corresponding gear. The measurements were made using the strain gauges mounted on the Cardan shaft and connected with the software for data processing. In table 1. the values of the measured maximum torque on the Cardan shaft are given. Combining the results obtained by interview for the percentage participation stages of transmission and statistically analyzed results of measurement, load spectrums for all gear pairs were formed (Figure 2) (except for the sixth speed, direct gear) on which the participation of torque in one million rotation of the gears was presented. The gear pair 0 participates in work of all stages of transmission, except when working sixth gear pair.

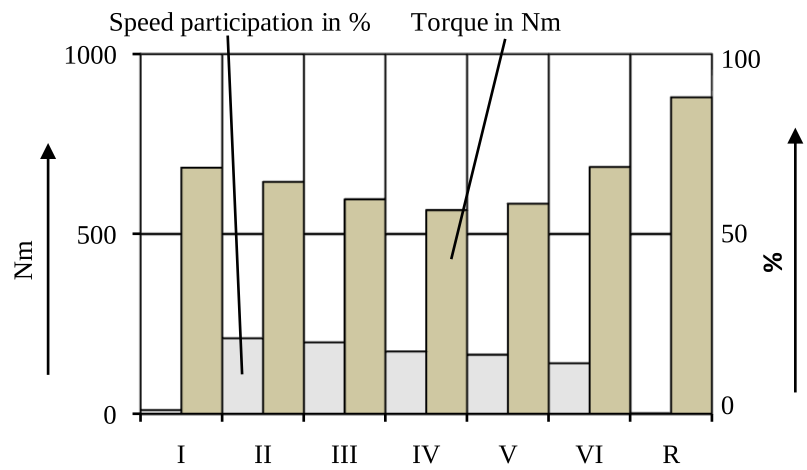

Figure 1. Participation speeds and torque for representative operating conditions

Ratio $x_i=T_i/T_1$ is in relation 0…1, T_1 is maximal torque of the pinion of gear pair, T_{10} for gear pair 0, T_{11} for gear pair 1, T_{12} for gear pair 2, etc. Torque T_i is variable torque. Maximal torque T_1 for the pinion of every gear pair is obtained by recalculation (deduction) of gearbox maximal output torque presented in table 1.

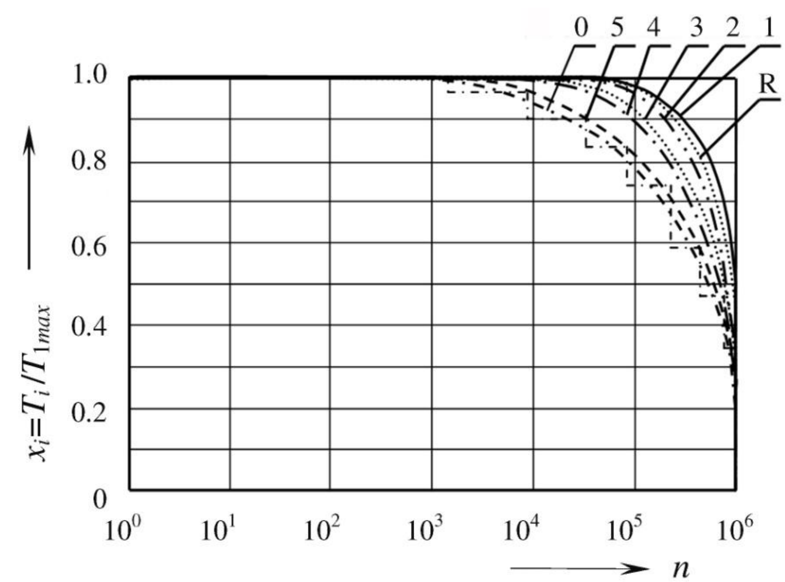

Figure 2. Load spectrums for the pinions of every gear pairs

Reliability of Gearbox

Total reliability of the box gear consists of individual reliability gear, the reliability of coupling, bearings, seals, etc. [8] [9][10]:

$$R = R_g R_b R_c R_{se} R_{lm} \tag{1}$$

Where are R_g - reliability of the gears against teeth flanks wear, R_b - reliability of the bearings, R_c - reliability of couplings, R_{se} - reliability of the seals, R_{lm} - reliability of the steering assembly. If the gearbox includes r

components, which are introduced in the model of reliability, assuming that the elementary reliability is same, the reliability of each of them is:

$$R_j = \sqrt[r]{R} \tag{2}$$

Where are:
$r=g+b+c+se+lm=7+7+4+2+1=21$
g- number of gear pairs;
b- number of bearings;
c- number of the couplings (three synchro couplings and one sleeve coupling for drive in reverse);
se - number of the seals
lm - number of the steering assembly
In this model, the partial reliability of the gear can be represented by following equation:

$$R_x = R_{g0} R_{g1} R_{g2} R_{g3} R_{g4} R_{g6} R_{gR} \tag{3}$$

In (3) each of the elementary reliabilities R_{g0}, R_{g1}, R_{g2}, R_{g3}, R_{g4}, R_{g6}, R_{gR} is reliability of gear pairs embedded in gearbox, which when damaged should be replaced in pairs. The number of these reliabilities corresponds to the number of gear pairs x=7. Elementary reliability of each pair of gears is R_g=R_j according to the equation 2.
As for the gears, the reliabilities of synchro-couplings and bearings make a serial connection of elementary reliabilities.

$$R_y = R_{c1} R_{c2} R_{c3} \, ; \quad R_z = R_{b1} R_{b2} R_{b3} R_{b4} R_{b5} R_{b6} \tag{4}$$

Number of synchro couplings is y = 3, and the number of bearings in this gearbox is z = 6. Control system in terms of its failures is treated as one component p= 1. Number of the seals on the input and the output shaft is m=2.
Reliability of one pair of gears R_{gx} is complement of its unreliability F_{px}.

$$R_{gx} = 1 - F_{px} \tag{5}$$

Load Capacity Calculation

Calculation of load capacity implies that all design parameters, design properties of components and characteristics of materials and parts are known and defined. The load capacity of automotive gearbox is the result of load capacities for every speed of level that has to correspond to service load. The relation between load capacity and design parameters for a certain gear pair is:

$$b_x = \frac{T_{x1}}{2\left(\sigma_{Hdes}\right)^2 d_{x1}^2} \frac{u_x + 1}{u} Z^2 K$$

$$T_1 = \left(\sigma_{Hdes}^2 \frac{d_1^2}{2KZ^2} \frac{u}{u+1} \right) b = a\, b \tag{6}$$

In the formulas T_1 is the torque at the pinion (less gear in gear pair), d_1 is pitch diameter of the pinion, b is the gear pair width, $u=z_2/z_1$ is transmission ratio, z_1 – teeth number of the pinion, z_2 – teeth number of the gear. Load distribution in the gear teeth contact and load dynamics effect is included by value K, and contact conditions by value Z, all according to standards about helical and spur gear calculation ISO 6336 and DIN 3990. Design allowable stress σ_{Hdesj} is calculated in relation to elementary reliability for a corresponding gear pair j and all material and service characteristics including variation and randomness. For all gear pairs in the gearbox this relation has the form.

Software DRAG

Based on previously developed model for load capacity calculation of gear pairs, software DRAG, in which users have the possibility to calculate gear width or load capacity, is developed. In both cases, a limitation is the reliability that gearbox needs to meet after crossing a certain number of kilometers. In both variants constraints may vary. The software is consisted of five modules that allow solving the appropriate tasks. The first of these is the definition of allowable stress, the second module relates to the identification of gearbox load capacity with known design parameters, the third module in the software is the inverse calculation in relation to the other module where calculates the load or load capacity is carried out. The software is interactive, which means that the user during its application must make numerous decisions and enter certain information in the iterative approximation to the solutions. In this regard, the fourth module provides iterative optimization of design parameters and gearbox load capacity, while the fifth module enables calculation of gearbox bearings.

Conclusion

Reliability model of automotive gear box, specially designed and application-oriented for approach to Design for Reliability, is given in short form. This model is based on the application of experimental results in conditions (load spectra) in the exploitation of gearboxes, and application of the results of extensive research in the probability of failure of tooth flanks of gears, bearing and other components. The paper presents the load spectrums formed on the basis of experimental results for certain conditions of exploitation, as well as the way of determining the load capacity and load. For developed model the software for structural optimization was made.

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