# RELIABILITY DESIGN OF POWER TRANSMISSION

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***Abstract***

*With the worldwide competition so strong, it is essential for motor vehicles, regarding to power transmission, to have high reliability. The reliability design is one of the ways to reach this objective. The stage of design is the most important one in the life cycle of a power transmission. Reliability design, within the designing stage, correlates directly with the power transmission reliability. The problem of a practical power transmission, design has been solved by developing of a methodology suited to the purpose. The basis of the developed design represents a contemporary approach to designing, comprising the phases of conceptual, preliminary and detail designs, with applying of the reliability design method within these phases. Approach to technical system design, the algorithms of the developed vehicle design from market-users by reliability preliminary design, detailed reliability design to manufacturing, reliability block diagram are presented in the paper. The developed and applied methodology enables reliability design of the vehicle and its elements, with the objective of obtaining a reliable vehicle which is one of the main requirements for the competitiveness in the market of automotive vehicles.*

***Keywords:*** *power transmission, stage of design, reliability design, design of a power transmission*

## 1. Introduction

The complexity and responsibility in the process of power transmission design as expressed through particular requirements regarding reliability and considering performances and other quality characteristics of the power transmission e as a whole, requires a systemic approach to reliability design.

The existing reliability design methods for technical systems have been developed on various bases and it is difficult to determine the most suitable one for the reliability design of power transmission. Having perceived this problem, as well as the need for an up-to-date system approach to motor vehicle designing, with the phases of conceptual, preliminary and detail designs, it has been concluded that it is possible to integrate some of the methods, i.e. their development bases, into one entity within the motor vehicle reliability design methodology.

In accordance with the above stated the paper shows the application of the developed reliability design methodology in the field of motor vehicles, namely power transmission with the phases of conceptual, preliminary and detail reliability designs.

## 2. The reliability design

In the field of reliability, reliability designing methods and techniques has been developed aimed to be applied in the phase of system design. In that respect, the vehicle reliability design, nameliy power transmision, has been developed, and in these paper presentations, the basis of which comprises the modern approach to technical system design, with its phases of concept, preliminary and detail design, as presented in Figure 1.

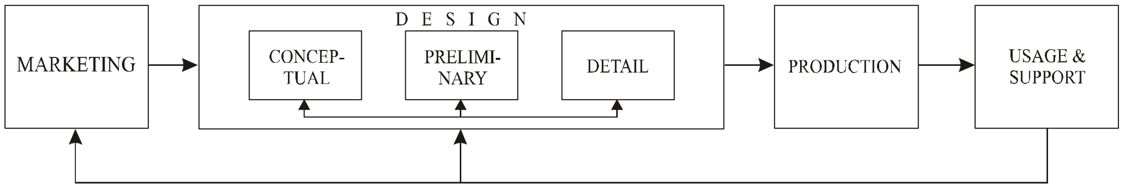


*Fig. 1. Approach to technical system design*

In accordance with the above stated, Figures 2, 3 and 4 shows the algorithm of the developed vehicle design in the form of a flow-diagram, which describes in a graphical manner the activities, their sequences and feedback activities within the stated reliability design phases.

### 2.1. Market – Users

According to algorithm (step 1, Figure 2), the process designing of a vehicle, as a system is starts by translating the user's requirements and needs into a design specification.

### 2.2. Concept Phase

For the translation of users' needs and requirements into quantitative and qualitative indicators, the **Quality Function Deployment –** QFD (steps 2 and 3, Fig. 2.) is applied.

**Reliability Specification** implies defining-designing of "$R_S(t)$" – power transmissions (as system -S) level, i.e. the defined system reliability value for the designed time t (step 4, Fig. 2). All checks in further phases lean on this value.

**Reliability Block Diagram** - RBD. On the basis of knowing the structure, and upon analysis of the manner of vehicle operation and analyses of the effect vehicle elements' failures have on orderly vehicle operation, RBD, Fig. 5, of the vehicle and its systems is formed (step 5, Fig. 2),

**Reliability Function -** RF. On the basis of the defined RBD and adopted exponential failure distribution, the reliability function is defined (step 6, Fig. 2):

$$R_S(t) = \prod_{i=1}^{n} R_i = R_1.(t)(R_2(t)R_2(t)R_4(t) = e^{-t\sum_{i=1}^{4}\lambda_i} = e^{-\lambda_{PT}\cdot t} = e^{-\lambda_S \cdot t}\,, \tag{1}$$

where:

$R_S(t)$, $\lambda_S$, - reliability and failure rate power transmission (as a system-S),

$R_i(t)$, $\lambda_I$ - reliability and failure rate subsystem i:1-Clutch, 2-Gearbox, 3-Universal joint, 4-Rear axle.

**Predicting Reliability.** On the basis of the researched literature and power transmission in operation reliability research, (step 7, Fig. 2), i.e. the value between the following values is adopted:

$$\lambda^*_{\min} \langle \lambda^*_{ado} \langle \lambda^*_{\max}\ . \tag{2}$$

**Reliability allocation.** Allocation of the system reliability function is done by applying of the *equal distribution method* $\lambda_i^{**}$ and the *AGREE* $\lambda_i^{***}$ method /2/ i.e.:

$$\lambda_i^{**} = \frac{1}{n}\lambda_S = \frac{1}{n}\cdot\frac{-\ln R_S(t)}{t}\,, \tag{3}$$

$$\lambda_i^{***} = \frac{n_i\left[-\ln R_S(t)\right]}{n\cdot E_i\cdot t_i}\,, \tag{4}$$

where:

$\lambda^*_{\min}$, $^*$ $\lambda^{**}$ado, $\lambda^{***}_{\max}$,- min., adopted and max. value of failure rate,

$\lambda_S$ - the laid down system failure rate,

n, $n_i$ - total number of system elements, total number of elements of the i-th subsystem,
$E_i$ -the subsystem significance degree,
$t_i$ - time of operation of the i-th subsystem.

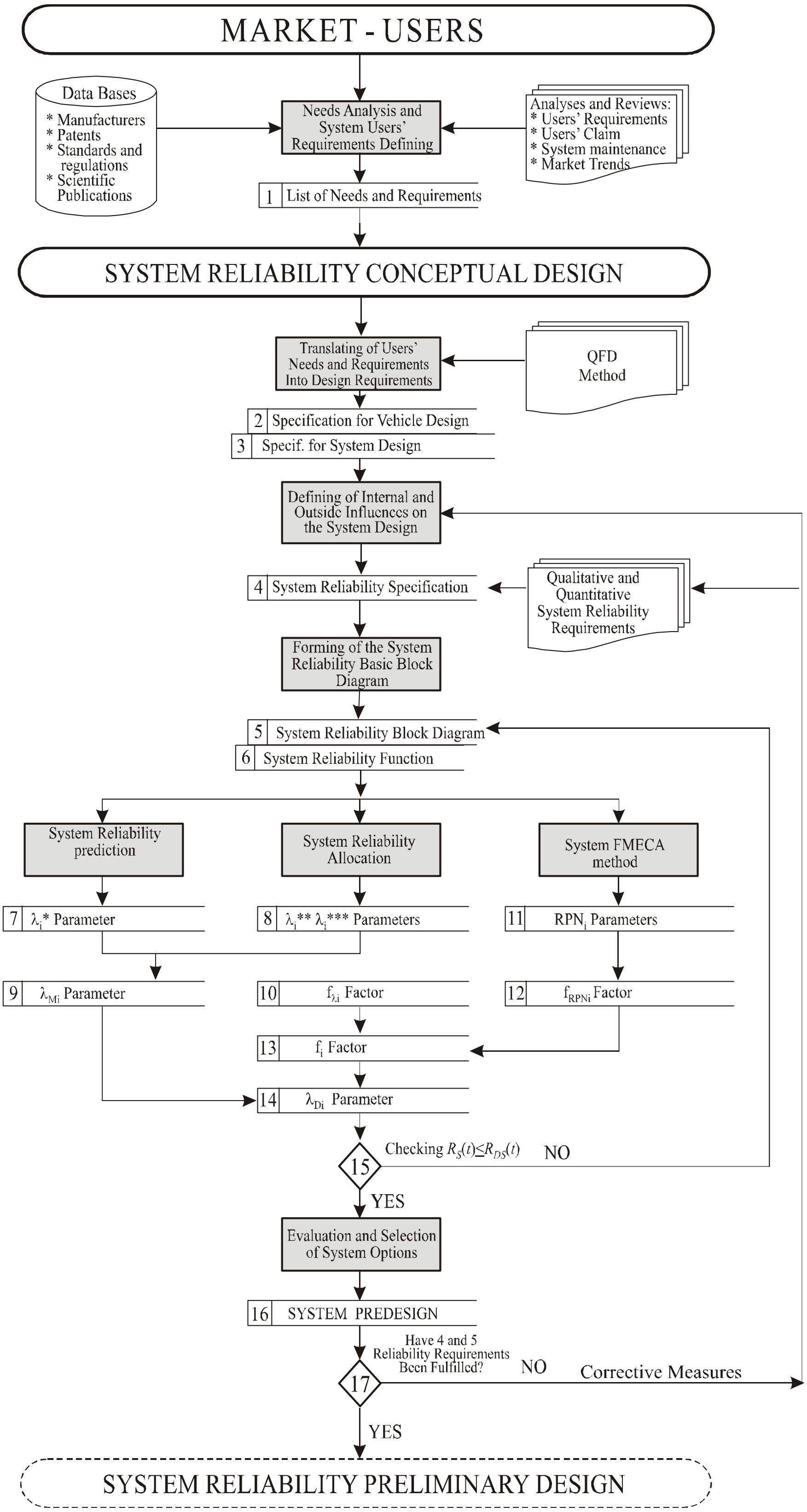


*Fig. 2. The algorithm of the process designing of a vehicle from market-users to reliability preliminary design (steps from 1 to 17)*

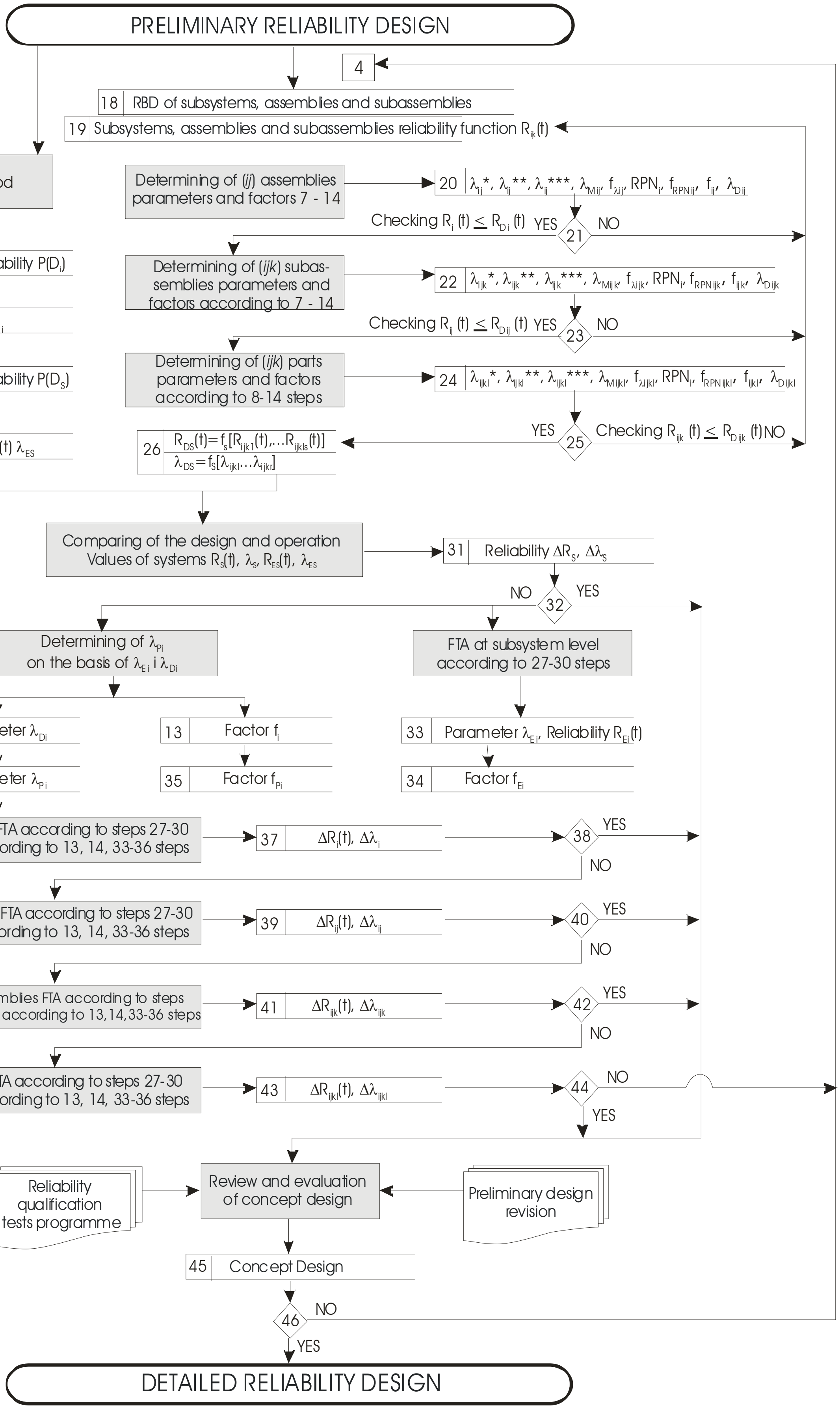


*Fig. 3. The algorithm of the developed vehicle design: from preliminary reliability design to detailed reliability design (steps from 18 to 46)*

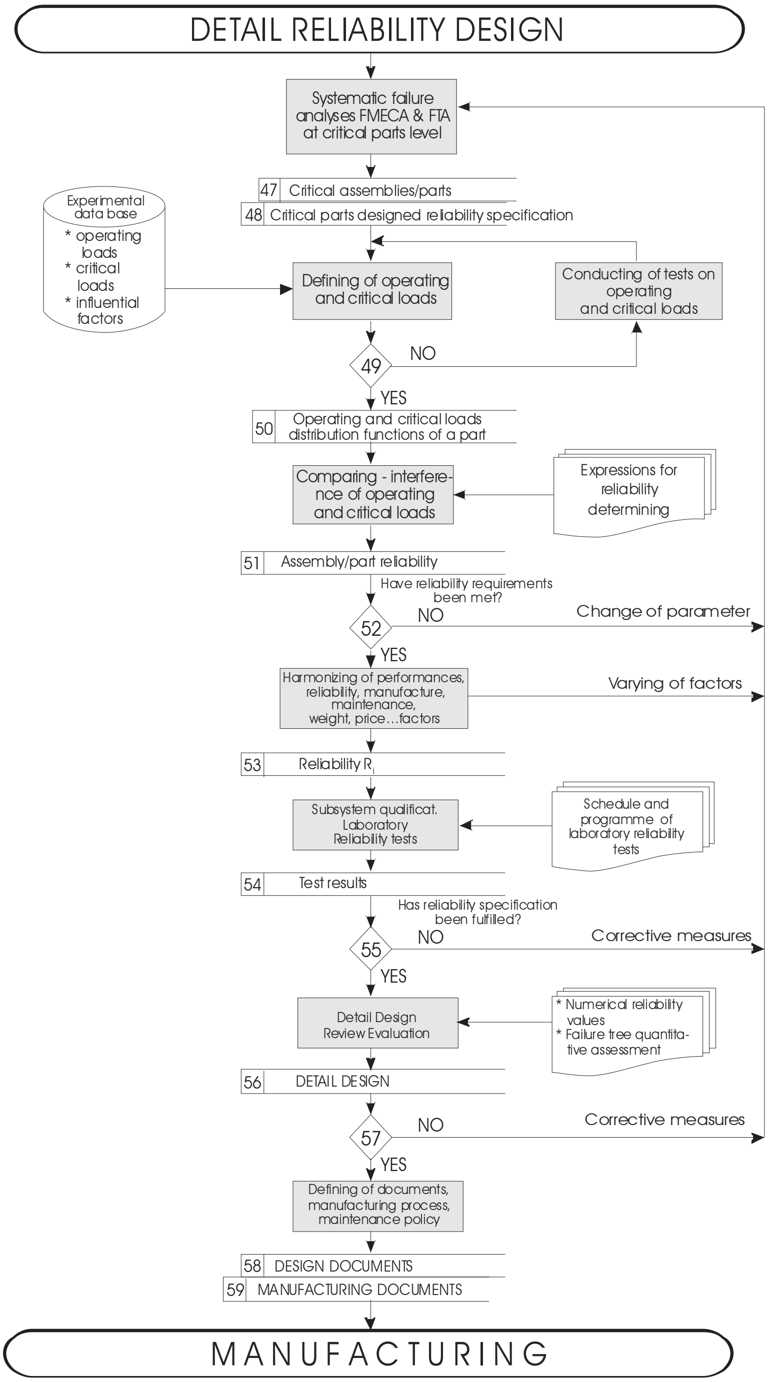


*Fig. 3. The algorithm of the developed vehicle design: from detailed reliability design to manufacturing (steps from 47 to 59)*

Applying the Failure Mode, Effects and Criticality Analysis [8] method, assessment of system elements failures criticality is determined, $RPN_i$ and $f_{RPNi}$, (step 11 and 12, Fig. 2), in the form:

$$f_{RPNi} = \frac{\dfrac{1}{RPN_i}}{\sum_1^n \dfrac{1}{RPN_i}} = \frac{\dfrac{1}{PF_i \cdot FDV_i \cdot PFR_i}}{\sum_1^n \dfrac{1}{PF_i \cdot FDV_i \cdot PFR_i}}, \quad (5)$$

where:

$RPN_i$, $PF_i$, $FDV_i$ - failure criticality degree assessment, occurrence probability, effect gravity,
$PFR_i$, $f_{RPNi}$ - probability of failure detection and failure criticality factor.

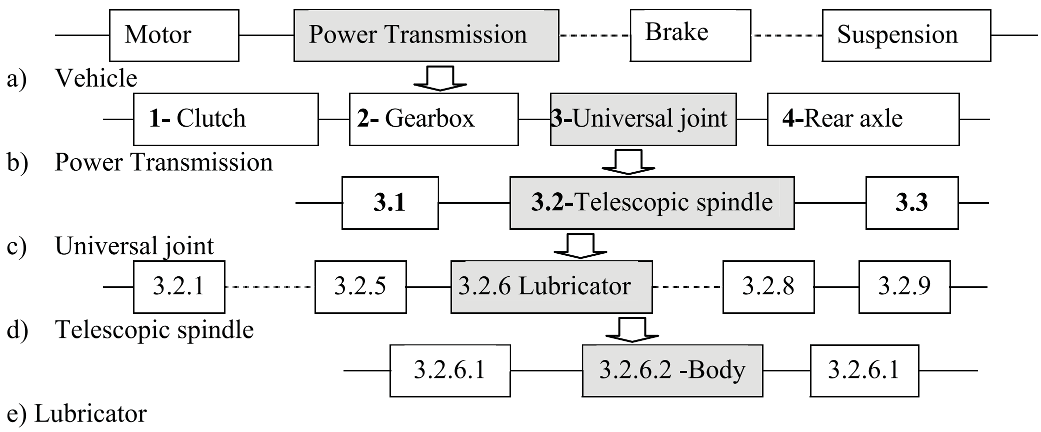


*Fig. 5. Reliability Block Diagram*

On the basis of $\lambda_i^*, \lambda_i^{**}, \lambda_i^{***}$ and the $f_{RPNi}$ $\lambda_{Di}$ is determined as (step 9., 13. and 14., Fig. 2.):

$$f_{\lambda i} = \frac{\lambda_{Mi}}{\sum_{i+1}^{n} \lambda_{Mi}} = \frac{(\lambda_i^* + \lambda_i^{**} + \lambda_i^{***})/3}{\sum_{i=1}^{n} [(\lambda_i^* + \lambda_i^{**} + \lambda_i^{***})/3]} = \frac{\lambda_{Mi}}{\lambda_{DS}}, \tag{6}$$

$$\lambda_{Di} = \frac{f_{\lambda i} + f_{RPNi}}{2} \lambda_{DS} = f_i \cdot \lambda_{DS}\,. \tag{7}$$

**Checking .** Verification of the set $\lambda_S$ and $R_S(t)$ values, and of $\lambda_{DS}$ and $R_{DS}(t)$ designed ones, is done in such a way that the following condition is satisfied (step 15., Fig. 2.):

$$R_S(t) = e^{-\lambda_S t} = e^{-t\sum_1^n \lambda_i} \le R_{DS}(t) = e^{-t\sum_1^n \lambda_{Di}} = e^{-\lambda_{DS} t}, \tag{8}$$

where:

$\lambda_{Mi}$ - failure rate mean value,

$\lambda_{DS}$, $\lambda_{Di}$ - system and elements failure rate *designed* value, respectively,

$f_{\lambda i}$ - failure rate factor,

$f_i$ - failure rate mean value factor.

$R_{DS}(t)$ - designed reliability value of the designed time *t*.

### 2.3. Preliminary Phase

Upon determining of $\lambda_{Di}$ within the conceptual reliability design, preliminary reliability design of subsystem, assemblies, subassemblies, elements is performed by applying of the reliability design method in accordance with the established sequence (steps from 18 to 46 in Fig. 3) by applying of equations from (1) to (8). The activities and documents, control points for evaluation and assessment of satisfying of the reliability requirements and the principle of feedback, all provide for selecting of the most acceptable solution.

**Comparing of the Designed with Operational Reliability Values.** In this stage, checking of reliability and failure rate of the system's elements is performed, i.e. $\lambda_{DS}$ and $R_{DS}(t)$, $\lambda_{Di}$ and, $R_{Di}(t)$ correction, from the point of view of their realization in exploitation. By way of the *FTA Method* /7/, failure probability, i.e. the reliability is determined of that or similar vehicle and its elements in exploitation, by applying of the expression (by step 27., 28., 29. 30, Fig.3):

$$R_{ES}(t) = e^{-\lambda_{ES} t} = e^{\frac{\ln R_{ES}(t_E)}{t_E} t} = e^{\frac{\ln[1-P(D_S)]}{t_E} t} = e^{\frac{\ln\left[1-\sum_{i=1}^{n} P(D_i)\right]}{t_E} t}, \tag{9}$$

and then, concurrence is checked by applying of expressions (9) for $\lambda_{DS}$ and, $R_{DS}(t)$, (steps 31 and 32, Fig. 3) according to the following:

$$(\pm)\Delta\lambda_{DES} = \lambda_{DS} - \lambda_{ES}, \qquad \text{and} \qquad (\pm)\Delta R_{DES}(t) = R_{ES}(t) - R_{DS}(t), \tag{10}$$

where:

- $D_i, P(D_i)$ - failure, i.e. failure probability of the i-th subsystem component,
- $P(D_S)$ - system failure probability, i.e. that of the system elements in the course of exploitation,
- $(\pm)\Delta R_{DES}(t)$ - the difference between the system's designed and exploitation reliabilities,
- $(\pm)\Delta\lambda_{DES}$ - the difference between the system failure designed and exploitation intensities,
- $R_{ES}(t_E)$ - reliability determined in exploitation during $t_E$ (operation in the course of exploitation),
- $R_{ES}(t)$ - reliability determined on the basis of $R_{SE}(t_E)$ for t,
- $\lambda_{ES}$ - failure rate determined in exploitation.

**Correction of Reliability Designed Values.** If the result obtained in accordance with the expression (10), i.e. (11) is "+", it is not needed to perform the $\lambda_{Di}$ and $R_{Di}$ correction. Otherwise, correction is done by the factor $f_i$ i $f_{Ei}$, i.e. $f_{Pi}$ in the form of,

$$\lambda_{Pi} = \frac{f_i + \lambda_{Ei} / \sum_{i=1}^{n} \lambda_{Ei}}{2} \frac{f_i + f_{Ei}}{2} \lambda_{DS} = f_{Pi}\lambda_{DS}, \tag{11}$$

where:

- $\lambda_{Pi}$ - failure rate determined in the preliminary phase,
- $\lambda_{Ei}$ - failure rate of vehicle elements determined in exploitation,
- $f_i$, $f_{Ei}$ and $f_{Pi}$ - are the factors of conceptual exploitation and preliminary designs respectively.

Upon establishing of $\lambda_{Pi}$, the difference $\lambda_{Pi}$ and $\lambda_{E,i}$ is determined (step 37-43, Fig. 3):

$$(\pm)\Delta\lambda_{PEi} = \lambda_{P.i} - \lambda_{E.i} \qquad \text{and} \qquad (\mp)\Delta R_{PEi}(t) = R_{Ei}(t) - R_{Di}(t), \tag{12}$$

If the result obtained in accordance with expression (12) is "+", the exploitation value of the elements' failure rate is kept. Otherwise, the failure rate is to be reduced, i.e. elements' reliability is to be raised and adjusted with the designed value, i.e. with the manufacturing capabilities, or redesigning of the system elements' reliability is to be performed.

## 2.4. Detail reliability design

Verifying and possible rising of reliability is done in the phase of detail reliability design (step 47-59, Fig. 4.) by applying the *method of overlapping of operating and stress-strength* load values, i.e. stress, by applying the following expressions,

$$R = \frac{1}{\sqrt{2\pi}} \int_{-\frac{m_r - m_k}{\sqrt{\sigma_r^2 + \sigma_k^2}}}^{\infty} e^{-\frac{1}{2}z^2} dz = 1 - f(|z|), \qquad z = -\frac{m_k - m_r}{\sqrt{\sigma_r^2 + +\sigma_k^2}}, \tag{13}$$

where:

- R - reliability of a component, determined on the basis of operating and stress-strength stresses,
- $m_k$ and $\sigma_r$ - mean value and standard operating load discrepancy,
- $m_r$ are $\sigma_k$ - mean value and standard stress-strength load discrepancy,
- z - lower limit of the random variable standardized normal distribution.

According to this checking, the proceedings of corrective measures (change of material, manufacturing technology and/or sizes), so that in case some values are impossible to improve, redesigning of reliability is performed.

### 2.5. Data bases

Examining of operating loads in motor vehicle elements has been made with the objective of establishing of a database. Stress-strength loads of elements have been defined on the basis of the experimentally obtained parameters of the law on material strain distribution at yield point and on the basis of influential factors acting on the dynamic durability [5].

On the basis of the automotive vehicle reliability research, databases have been formed on the forms and intensities of the vehicle failures, i.e. on the power transmission system elements [1].

## 3. Conclusion

In the contemporary process of designing of vehicles and their elements (systems, subsystems, assemblies, subassemblies and components), it is necessary to design vehicle reliability as well. With that objective in mind, the methodology of vehicle reliability design has been developed. This methodology, with its phases of conceptual, preliminary and detail designs, and the feedback mechanism, is based on reliability predicting and allocating, RBD, RF, FMECA and FTA.

Upon defining of the vehicle users' requirements by applying of QFD method, the vehicle reliability specification is defined in the phase of conceptual design and designing of the vehicle systems reliability is performed together with checking of the set requirement regarding the vehicle reliability level. The phase of preliminary design covers designing of reliability of subsystems, assemblies, subassemblies and components and their checking from the standpoint of reliability characteristics in operation, as well as proposing of corrective measures. The phase of detail reliability design relates to calculating and checking of vehicle elements loads from the point of view of reliability, as well as to proposing corrective actions to be taken.

Data bases of operating and stress-strength loads and vehicle failures, have been formed. For this purpose, operation research work has been conducted on operating load regimes, and the failure distribution laws parameters have been defined.

On the basis of the presentation in this paper, it can be concluded that the developed and applied methodology enables reliability design of the vehicle and its elements, with the objective of obtaining a reliable vehicle, which, in any case, is one of the main requirements for the competitiveness in the market of automotive vehicles.

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