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# ANALIZA DEGRADACJI POJAZDÓW W EKSPLOATCAJI

# AN ANALYSIS OF DEGRADATION OF VEHICLES IN OPERATION

*Pojazdy mechaniczne są stosunkowo złożonymi obiektami technicznymi w których w trakcie funkcjonowania zachodzą złożone procesy zużycia. Intensywność zużycia poszczególnych zespołów pojazdu jest uzależniona nie tylko od ich konstrukcji, ale także od warunków ich eksploatacji. W niniejszym artykule przestawiono mechanizmy i czynniki wpływające na degradację pojazdów mechanicznych.*

*Słowa kluczowe:* stan techniczny, zużycie części, degradacja pojazdu.

*Vehicles are quite complex technical objects and complicated wear processes accompany their exploitation. The intensity of degradation of particular systems of a vehicle depends not only on a construction but also on the exploitation conditions. In the following paper the mechanisms and conditions influencing degradation of vehicles have been presented.*

*Keywords:* technical state, wear, degradation of vehicle.

## 1. Introduction

Changes in the technical condition of a vehicle depend on its sensitivity to degradation processes and the intensity of operational external loads. The effects of external loads originating in various operational situations accumulate during vehicle operation.

Knowing the characteristics of the sensitivity of vehicle elements to physical degradation and the spectrum characteristics of mechanical, heat and physicochemical loads, it is possible to estimate, with certain probability, the time when the state of fitness changes into a state of unfitness.

The change in the technical condition of a vehicle is chiefly a random process, which depends at the same time on various external forces, resulting in damages that can be sudden, accumulated and relaxing. This means that for various vehicles, the change of the examined condition will be different, and it will be characterized by different types of wear curves.

Generally, it can be stated that progressive degradation of a vehicle is a complex process, which depends on the accumulation of various tribological, fatigue, corrosive and other effects.

Therefore, the analysis of vehicle degradation aims at providing information in order to make certain decisions, through generating the data of the vehicle degradation process, which determine the risk of unfitness.

This requires an explanation of the core problems related to an assessment of the physical and mechanical phenomenon of the degradation of vehicle elements and the application of proper models in order to map the course of the vehicle operation process [2, 3, 4].

## 2. Formulation of the problem

Models representing degradation of vehicles and their elements should allow for long-term forecasting of changes in their conditions, and through this, facilitate optimization of the distribution of financial means allocated for their maintenance. Hence, there are a large number of solutions and degradation models which can be encountered while analysing vehicle maintenance systems. However, they all come down to the strategy of mixed maintenance according to constant schedule of technical inspections and annual standard checks of technical condition.

Generally, the level of vehicle degradation can be described during the $i^{th}$ period of operation by the following relation [2, 4]:

$$D_i = D_p + R_i \cdot \lambda_i - P_i \cdot \mu_i \qquad (1)$$

where: $D_p$ – level of vehicle degradation at the beginning of the assessment, $R_i$ – indicator of operational reliability, $P_i$ – a technical inspection parameter, $\lambda_i$ – intensity of usage, $\mu_i$ – intensity of operation, $i$ – $i^{th}$ period of operation.

The essential variables, besides time, influencing degradation processes of a vehicle, are:
- heat load,
- mechanical load,
- chemical processes (corrosion) depending on humidity and other environmental impurities,
- weather conditions, road conditions and random events,
- individual characteristic of a driver (driving style),
- quality of repairs and used appear parts.

Therefore, the process of vehicle degradation depends on many external forces and requires a system analysis.

On the basis of the assessment of the vehicle wear (according to statistical research carried out by experts), the function of degradation is presented in Figure 1.
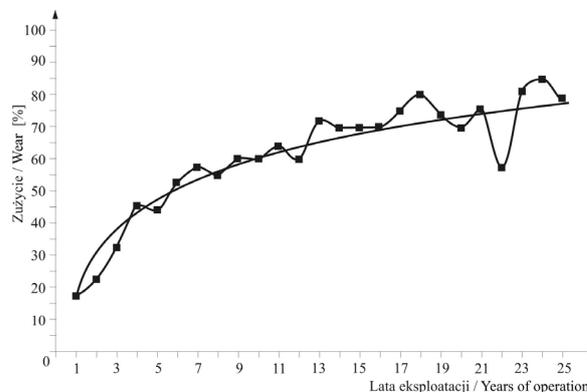


*Fig. 1. Process of vehicle degradation depending on the period of operation*

On the other hand, on the basis of DIN 31051 standard, the changes in machine wear during the operation is presented in Figure 2.
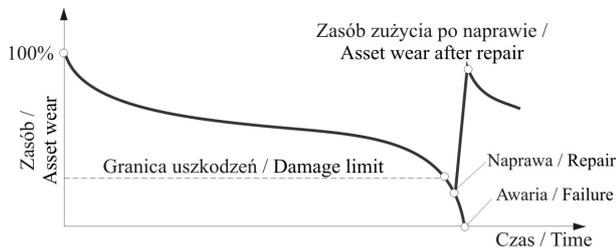


*Fig. 2. Change of asset wear during operation [according to DIN 31051]*

After [2], degradation degree ($S_D$) of the vehicle depends on its operational period (t) and the intensity of operational factors:

$$SD = < \lambda(c_i), \quad i = \overline{1,n}, \quad t > \quad (2)$$

The approximation of the model regarding the assessment of the degradation degree of a vehicle should therefore include an assessment of its initial (designed) strength, estimation of the operational factors' history (loads of various types) and an assessment of the residual strength.

Calculations of construction elements strength during the operation under random and accumulated loads requires knowledge of their processes and their distribution in relation to the material of a given construction element. In a diagrammatic form, the issue of operational strength is presented in Figure 3.
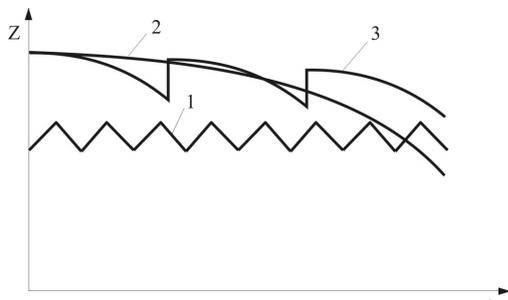


*Fig. 3. A diagram describing the effects of external loads: 1 – mechanical loads, 2 – tribological wear, on the vehicle strength, 3 – taking into consideration subsequent repairs*

Knowing the characteristics of the resistance of vehicle elements to destruction and spectrum characteristics of external loads, it is possible to estimate, with certain probability, the time when its technical condition will change, taking into consideration various mechanisms of wear. In the vehicle operation, the following mechanisms of element wear are distinguished [2, 4]:

– tribological wear processes (abrasive, oxidation);
– fatigue wear (pitting and fretting);
– cavitational wear (e.g. slide bearings);
– corrosive wear of vehicle elements due to chemical or electrochemical processes;
– thermal wear with intensive oxidation, e.g. elements of exhaust system and with local melting of surface layer, e.g. exhaust valve heads and seats.

## 3. Types and mechanisms of element destructions

Vehicle elements are operated in a system, the diagram of which is presented in Figure 4.
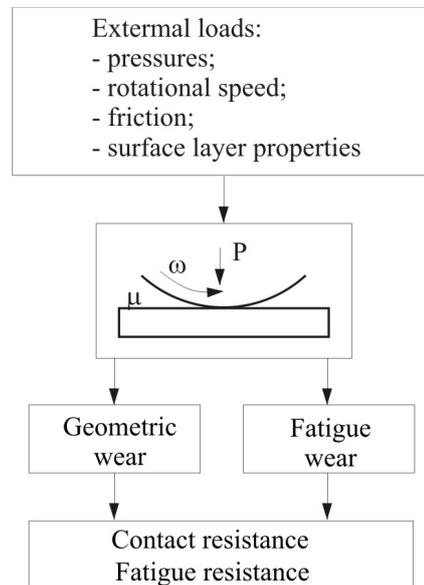


*Fig. 4. The diagram of the system of destruction regarding elements of pad-welded vehicles [1]*

Working out of the general model of degradation of a vehicle is nowadays practically impossible because of its complex construction and simultaneously wear of particular mechanisms. At present there are worked out the exact models of wear and durability of particular mechanisms. In the paper [4] there are presented the exemplary calculations of the durability of the drive shaft of a vehicle.

Most often, various forms of element wear (quasistatic and dynamic) occur at the same time during the operational period of the machine.

In classical models of wear, a loss in the surface of the material is made in the presence of plastic micro- and macroscopic deformations, leading to cracks. The stress destroying individual roughness protrusions, $\sigma_F$, can be described by Griffith-Irvin-Orowan equation:

$$\sigma_F \cong \sqrt{\frac{2E(\gamma + \gamma_p)}{\pi C}} \quad (3)$$

where: $\sigma_F$ – breaking stress for roughness protrusions, $\gamma$ - surface energy, $\gamma_p$, $\sigma_F$ - energy of plastic deformation, $C$ – the length of a possible crack.

For elastic contact the number of cycles to destruction can be determined from expressions 4 and 5 [1]:

$$n_S = \left(\sigma_O / \sigma\right)^{t_s} \quad (4)$$

$$n_S = \left(\sigma_O / \psi\tau\right)^{t_s} \quad (5)$$

where: $n_s$ – the number of cycles to roughness smoothing in elastic contact, $\sigma_o$ – short-term resistance, $\sigma$ – normal stress in contact, $\tau$ – shearing stress in contact, $\psi$ – coefficient (3÷5), $t_s$ – material constant (3÷14).

In case of plastic contact, typical for low cycle destruction, the number of cycles to destruct roughness in contact is determined from the following relation:

$$n_P = \left( e_O / e \right)^{t_P} \qquad (6)$$

where: $n_p$ – the number of cycles to roughness smoothing in a plastic contact, $e_o$ – critical strain to the destruction of material, $e$ – deformation as a result of friction, $t_p$ – material constant $(2 \div 3)$.

The speed of the development of a fatigue crack is a particularly important problem as regards pad welded elements. Padding welds shorten the time of initiating fatigue cracks, therefore information concerning the advancement of crack in them becomes essential. A padding weld partly changes the microstructure of an element and introduces discontinuities and residual stresses. The knowledge of the effects of the above mentioned factors on the speed of the fatigue crack growth can significantly facilitate and increase the accuracy of theoretical forecasting on the stage of designing the durability of pad welded elements.

## 4. Summary

This study has revealed a lack of a comprehensive view of vehicle degradation in the process of operation.

As follows from theoretical considerations and experimental research, the description of the vehicle degradation process must take into account many qualitative and quantitative aspects of wear and fatigue.

It is necessary to take into consideration the degree of vehicle degradation already at the designing stage, in order to develop a rational operational strategy, which leads to optimization of the allocation of financial means for vehicle maintenance.

Developed models of degradation in the form of a degradation function provide a general relation of the assessment of wear condition to the operational period. The presented curves of degradation, provided in the form of a function, do not take into consideration simultaneous occurrence of mechanical and heat loads, corrosion or renewal elements as part of conducted technical inspections.

In many cases, the vehicle degradation assessment can be based on Wöhler's fatigue strength diagram. It seems that it should be completed by the course of the σ-N line of constant probability (P) of construction destruction, by the effects of the renovation of elements (e.g. pad welding with the use of Smith's chart), etc.

Collected statistical data concerning the process of operating individual types of vehicles do not make it possible to forecast a degradation curve, taking into consideration the intensity of the real loads and accumulation of damage.

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