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STOCHASTIC MODEL OF TRUCK ENGINE WEAR WITH REGARD TO DISCONTINUITY OF OPERATION

The influence of operational factors on the wear process of the truck engine parts was analysed. Discontinuity of engine operation was found to be a crucial factor. Contribution of start-ups, following breaks in operation in total wear of the engine is significant and in case of investigated engine amounts 40%. As wear of engine parts accompanying a single start-up strongly depends on the temperature, cold start-ups (usually first in the morning) are of particular importance.

Taking above into consideration the authors suggest modelling the course of wear as a stochastic process with the following constituents:
  - *transmission process with linear realization representing average value of wear,*
  - *stationary process with periodical realization representing deviations of wear intensity in particular seasons accompanying cold start-ups,*
  - *stationary process of statistic fluctuations with random time realizations, representing instantaneous deviations of wear in relation to average values.*
Mathematical model was illustrated with some empirical results.

Keywords: *diesel engine, wear, cylinder liner, durability prediction*

1. Introduction

Stochastic models of mechanical wear of engine cylinders are frequently used for accelerated investigations of engine durability. Such models most often describe growth-rate of cylinder diameter as a function of vehicle operation time.

Analysing process of friction, which is the cause of cylinder wear, it can be assumed that this wear is a sum of three separate components. The first component is wear occurring during quasi-steady, continuous engine operation. In such conditions wear intensity of cylinder liner is relatively small. The second component is so called start-up wear. It takes place only during putting engine in motion. The third component are random processes of surface degradation produced by instantaneous random inputs. Increments of wear caused by this component are rather small.

2. Mathematical model

The mathematical model was worked out on the basis of already described foundations (Niewczas 1989, Niewczas 1993):

$$Z_t = Z_0 + Vt + A_z \sin\left(\omega t + \phi\right) + \Sigma\Delta\Psi_r\left(t_j\right) \quad (1)$$

where: Z_t – non-stationary stochastic wear process, Z_0, V – variables independent of time, where Z_0 is initial wear and V is stabilized wear intensity, $A_z sin(\omega t+\phi)$ – one-dimensional stationary process with periodic re-alization, where both amplitude A_z and pulsation ω are constant, but the initial phase ϕ is a random variable with uniform distribution, $\Sigma\Delta\Psi_r(t_j)$ – one-dimensional, normal stationary process with expected value of zero and random variable realization, t – time, $t \in [t_p, t_m]$, where $t_p \geq 0$ is the initial time and t_m denotes the moment of exceeding the limit wear.

The model consists of three units. The expression $Z_0 + Vt$ constitutes the first unit, and is the evolutionary constituent of the wear – this unit is also named as the transmission process. Transmission process describes average wear change observed in long period of time, and is a sum of quasi-steady and start-up wear.

The second unit represented by the expression $A_z sin(\omega t+\phi) = \Psi_{\omega t}$ constitutes periodical component of wear changes, which describes cyclic deviations of wear from the value determined by the transmission process. In described model it is assumed that this deviations mostly results from different temperatures of cold start-ups (usually only the first start-up in the morning, at most two start-ups a day) in particular seasons.

The third unit, namely expression $\Sigma\Delta\Psi_r(t_j) = \Psi_{rt}$ constitutes the random component of the wear changes – also named as the random fluctuation process. Fig. 1 presents the model described above.

The model gives new explanations of the reasons responsible for the origin of failures of tribological systems in IC engines. Exceeding the limit wear by the
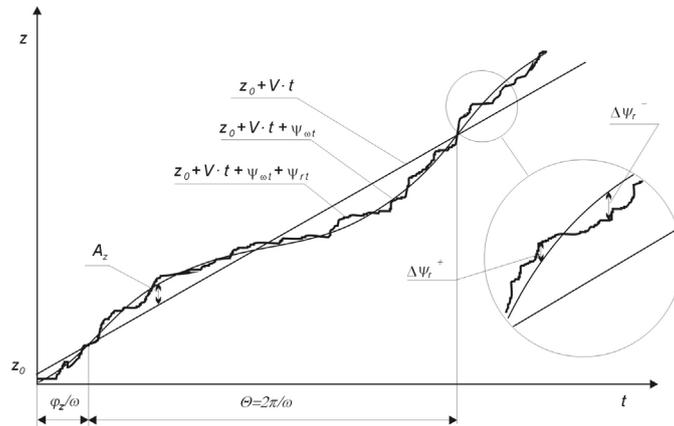
Fig. 1. Exemplary realization of the wear process Z_t and its constituents

fluctuation process is the direct cause of the failures. Initially, the wear fluctuations have negligible effect on the engine operation. However together with increase of engine wear during its operation and together with getting close to the limit wear level, fluctuations become more and more important. Evolutional component effect consists in the systematic increase of damage occurrence probability.

3. Results of experimental research

Results of previously conducted research (Nie-wczas 2003, Drozdziel 2003) were applied for the described model. The object of research was 4-cylinder diesel engine with displacement of 2.4 dm³. The engine is mounted in a delivery vehicle of maximum total weight of 2.9 ton. Results were gathered during both test-bed and on-road research of the engine.

In long term interurban and urban operation (240 km daily, 55,000 km annually) number and conditions of start-ups were measured. Distribution of start-up frequency (distances covered between successive start-ups) is shown on fig. 2a. It was found that engine start-up frequency averages 1 every 7 km. It was observed that over 85% of start-up realizations are

done at worm engine – temperature of engine coolant over 70 °C. Distribution of start-up temperatures is shown on fig. 2b.

On the basis of wear measurements of cylinder liners which were made after long-term operation (250,000 km) of two vehicles it was determined that mean wear intensities equal 2.07 μm/10,000 km and 2.16 μm/10,000 km. This quantity includes mileage component as well as start-up component of wear.

To find out the influence of start-up temperature on the cylinder liner wear a dedicated engine test stand was built. On this test stand multi-cyclic start-up tests in conditions of precisely controlled temperature (in the range from 15 to 75 °C) were carried out. It was established that average value of wear after 1000 engine start-ups at 15 °C equals 3.4 μm and at 75 °C – 0.5 μm (fig. 3).

Having number and temperature of start-ups and total cylinder liner wear intensity in long vehicle service as well as the increment of wear accompanying one start-up of the engine at given temperature it was possible to evaluate the contribution of start-ups to the total cylinder liner wear. In case of investigated engine this contribution equals 40%.
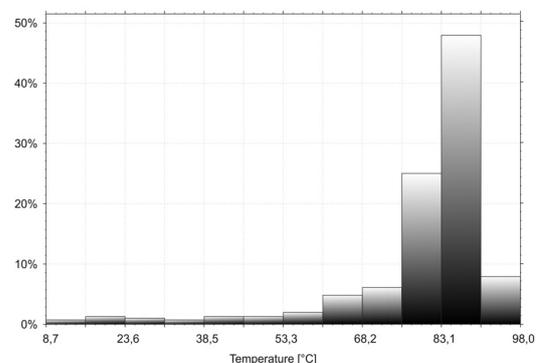
a)
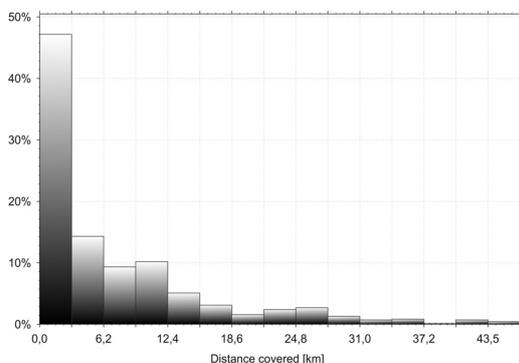
b)

Fig. 2. Start-up frequency of the engine (a) and coolant temperature during start-ups of the engine (b)
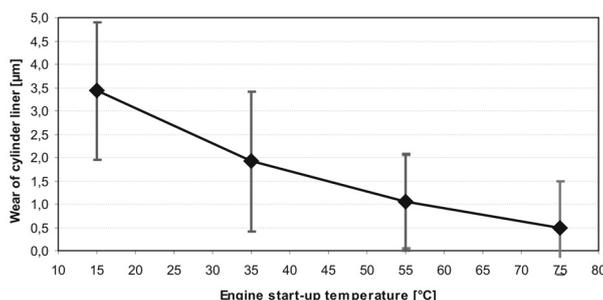
Fig. 3. Empirical dependence of cylinder liner wear in function of start-up temperature

Analysing the temperature of start-ups in particular seasons it was estimated that difference in the increments of start-up wear during winter and summer amount to several percents. It means that the amplitude A_z is not especially big but it should be mentioned that the vehicle in which start-up conditions were measured was kept in a garage (this is why the lowest start-up temperature is 8.7 °C).

4. Conclusions

Taking into account significant contribution of wear accompanying start-ups of an engine to the total wear and strong influence of engine temperature on the increment of wear during start-up it was suggested to describe the course of the cylinder liner wear of a vehicle engine with a stochastic model including a periodical constituent. This constituent describes changes of wear intensity during a year resulting from different temperatures of cold start-ups of an engine in particular seasons. Deviations of wear intensity described by the periodical constituent depend on a climate and manner of vehicle service. In case of investigated delivery vehicle, which was kept in a garage, it was estimated that 40% of the total cylinder wear comes from start-ups and intensities of wear in summer and winter differs in several percents.

5. References

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