Studying the Effects of Mechanical Loads and Environmental Conditions on the Drive-Axle Performance

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Abstract: The paper discusses the problem of achieving the required output parameters of a truck drive under various operating conditions. The authors enumerate the final-drive and differential mechanical efficiency, the pre-load torque in the final-drive bearing assembly, the friction coefficient, and the differential locking factor as the most significant technical parameters of the drive axle and its components. The main factors that affect these parameters during operation are: (i) mechanical loads that transmission is exposed to when transmitting the torque from the engine to the drive wheels; (ii) the effects of external thermal and dynamic loads when driving on an uneven surface or in cold / hot climates. The paper describes the main dependences between the final-drive processes and the inter-wheel differential processes; it also demonstrates how the aforementioned factors affect the output parameters of the component. The assumptions hereof are based on the results of bench and field truck tests, including adverse-climate tests. We herein propose a method for estimating the drive-axle load, which is based on the weighted values of the aforementioned factors. We prove it feasible to use auto-adjusted heating of the drive-axle components. The degree of thermal exposure shall be determined with due account of environmental conditions, surface conditions, engine and transmission parameters. The control algorithm is supposed to automatically take into account any change in one or more factors. This approach to controlling the output parameters helps improve the efficiency and the longevity of the drive axle and truck as a whole.

1. Introduction

In running vehicles, transmission parts and components can be in a largely varying condition while still staying within acceptable ranges of control parameters. It is extremely important to evaluate the current condition and the residual life of such components by means of on-board controls and continuous monitoring of operating parameters [1].

The authors' analysis of the technical condition of truck-transmission components allows proposing the following classification of the power transfer process factors in an engine—transmission—drive-wheel system. Temporary parametric deviation of a component for various reasons (including operation-induced change in temperature conditions). This factor expires as soon as the process ends or is de-intensified (e.g. when reducing the torque being transmitted).

Malfunction of the component, which may be caused by e.g. superficial wear. Such deviations are detected before an adjustment is applied (clearance- or angular-backlash adjustments, etc.) regardless of whether such adjustments are automated or not.

Component failure, e.g. shock-induced gear breakage or shaft jamming. This factor apparently results in a full-stop of the process and necessitates a repair.
Operating a vehicle implies using direct and indirect diagnostic parameters for evaluating the health and longevity of components [2, 3]. In this case, on-board control options do not include a number of direct-reading methods due to the disassembly and assembly operations being not an option, or due to using incompatible equipment. The authors believe the most efficient method consists in on-board status monitoring based on the following easy-to-control parameters:

Constant or situational noise during component operation. This parameter can be perceived as a certain type of sound waves (e.g. hum, howl, or knock sounds). Therefore, registering such readings necessitates allocation of amplitude and frequency ranges specific to various power-transfer factors and different components/parts.

Constant or situational vibration of a component. This parameter is also associated with specific frequency and amplitude ranges; as such, its registration is similar to that of noise.

Component/part temperature changes during operation. In this case, one has to monitor either the temperature of a single part that is crucial to the operation of its associated component, or the volumetric-average temperature of the whole component. The first option results in greater precision, but it is also more difficult to implement.

Oil level in the drive-axle crankcase adjusted for rotation-induced spattering. The oil volume also has to be adjusted for heating or cooling against the baseline.

Aside from these main parameters, it is imperative to take into account the location of noise/vibration/heat sources in the adopted coordinates.

2. Methods

As found in this research effort, on-board monitoring requires tuning the evaluation parameters according to the following criteria.

First, the parameter readings must be within the qualifying range with due adjustment for various factors, e.g. temperature increase or ingress of sand and dust in the transmission oil.

Second, shall multiple controlled parametric anomalies be detected (e.g. noise and vibration at the same time), the dominant affecting factor must be identified.

Further on, it is necessary to estimate the need for applying any adjustments so as to restore the process to its normal parameters.

If parameters remain deviant, such deviation must be evaluated against the maximum permissible deviation values. The most efficient way consists in monitoring the closeness to maximum permissible wear of the connection-to-check (the frictional couple).

If necessary, one can consider limiting the mechanical (and therefore, the thermal) impact shall the controlled parameters be approaching their respective maximum permissible values; to that end, one has to use parametrically-triggered disabling devices that shut down the engine and the transmission while also preventing component overheating (if a heating device is present).

For specific vehicle operations, causative factors behind such deviations must be identified. On-board monitoring of the most important evaluation parameters is a must. Those include: angular position of the steering wheel and the steered wheels; gear shift frequency and sequence; speed; braking frequency and intensity.

3. Results and discussion

Performance indicators fall into two groups: external (i.e. road bumps), and driver- or computer-controlled (speed, etc.). Therefore, we can specify possible ways to limit mechanical and thermal loads, as mentioned above.

Friction-induced losses in transmission components determine the mechanical efficiency of the final drive and the differential [4]. To ensure the rigidity of the final drive, it is important that the pre-load of the bearing assembly remains stable, which greatly depends on the temperature and the transmitted torque, experiments have shown [5]. Friction coefficient and differential locking factor also depend on mechanical and thermal loads.

The authors have found it reasonable to monitor the intensity of friction in the drive-axle components so as to reliable estimate the residual life of the truck transmission. We have identified the load parameters in heavy-duty applications, e.g. in moderate-climate winter.
4. Summary
The method for estimating the drive-axle load is based on the weighted values of the aforementioned factors. 
\[ U = \sum (\alpha_i R_i) \]
where \( \alpha_i \) are the factor weights; \( R_i \) is the factor significance for the given operating conditions.

In particular, paper [6] states that when preparing a vehicle for driving after being long-parked in an open lot, the final-drive thermal balance is found as follows:
\[ W_n = 3.6 \frac{(Q_1 + Q_2 + Q_3 + Q_4)}{t_{tp}} \]
where \( W_n \) is the power consumption of the on-board heater; \( Q_1 \) is the heat required for the drive-axle parts; \( Q_3 \) is the heat required for the transmission oil; \( Q_3 \) is the heat energy to be spent due to heat transfer to the environment when heating the final drive; \( Q_4 \) is the heat energy to be spent in unaccounted heat transfer processes; \( t_{tp} \) is the time to heat.

Apparently, reliable evaluation of the adjustments made by the automatic transmission-process control system requires objective data on the intensity of heat transfer in the drive-axle — environment system.

5. Conclusions
The assumptions hereof are based on bench and road test data on large-capacity trucks. Environmental effects were taken into account under low-temperature moderate-climate conditions as well as in simulated effects of impurities on the transmission oil in the drive-axle crankcase.

Equipment used for tests was compliant with test specifications and regulations. The identified errors and discrepancies of theoretical and experimental data are within acceptable range.

References
[1] Barykin A Yu., Basyrov R R, Mukhametdinov M M 2014 On the System Analysis of Operating Conditions for KAMAZ Wheel Drives (K voprosu sistemnogo analiza uslovy ekspluatatsii privoda kolyos avtomobiley KAMAZ) Scientific and Technical Volga Region Bulletin Is 6 pp 74-76
[2] Kulakov A T, Gafiyatullin A A, Barylnikova E P 2014 Providing normal conditions of lubricating of diesel engine during its operation IOP Conference Series: Materials Science and Engineering- V 69 Is 1 012027
[3] V V Lyandenbursky, M V Nefyodov, A S Ivlev et al 2015 Diagnosing the Final Drive in Trucks (Diagnostirovaniye glavnoy peredachi gruzovikh avtomobiley) Problems of Vehicle Quality and Operation: Use and Development of Vehicles [Problemy kachestva i ekspluatatsii avtotransportnykh sredstv: Ekspлуatatsiya i razvitiye automobilnogo transporta] pp 199–205
[4] K Lorenz, Ch Dietrich, E Donges 1986 The Influence of a Limited Slip Differential on the Traction and Handling of Rear Axle Driven Cars – Part 2 ATZ No 3 pp 149-153
[5] Mukhametdinov M M 2012 Studying the Intensity of Pre-Load Drops in KamAZ Final-Drive Anti-Friction Bearings In: Mechanical Engineering: Design, Engineering, Calculation, and Manufacturing and Repair Technology [Mashinostroeniy: proyektirovaniye, konstruirovaniye, raschyt i tekhnologii remonta i proizvodstva] pp 113–14
[6] A Yu Barykin, R Kh Takhaviyev 2017 Evaluating Energy Spent for Winter Operations of Truck Drive Axles [Otsenka zatrat energii v protsesse zimney ekspluatatsii vedushcheego mosta gruzovogo avtomobilya] Energy Saving. Science and Education (Energosberezheniye: Nauka i obrazovaniye): pp 52–57.
[7] Barykin A Y, Takhaviev R K, Samigullin A D 2018 The research of thermal processes of the automobile chassis International Journal of Mechanical and Production Engineering Research and Development. Vol 8 Special Issue 8 pp 458-64