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ANALYSIS OF ENGINE OILS USING MODERN METHODS OF TRIBOTECHNICAL DIAGNOSTICS

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Summary: The tribotechnical diagnostics (TTD) use lubricants as media that help obtain information about processes and changes in the systems that they lubricate. The methods TTD are used to determine optimum regular interval for oil exchange. The paper deals with possibilities of using modern instrumental methods in particular: infrared spectrometry with Fourier transformation (FTIR spectrometry), atomic emission spectrometry (AES) and analysis on particle counters for optimalization of change interval of engine oil.

Key words: tribotechnical diagnostics, analysis, engine oils, lubricants, FTIR spectrometry, atomic emission spectrometry, particle counters.

INTRODUCTION

The trend in the development of motor vehicles is primarily to keep achieving more power, higher reliability and safety of operation and, last but not least, economy and environment-friendliness of operation of motor vehicles. All these factors influence the demands on materials used for producing each component of transport vehicles, on monitoring the technical state of each part according to the recommendations of the producers of transport vehicles and on the quality of operational substances.

One of the most efficient methods of monitoring the technical state of vehicles is non-dismantling tribotechnical diagnostics (TTD). Tribotechnical diagnostics use lubricants as media that help obtain information about condition of machines.

Lubricant condition monitoring is widely accepted as preventive measures of premature machinery failures (1, 2).

Engine oil is a multi-functional element and is responsible a range of complex duties:

- lubrication of moving engine and reducing friction and wear of metal surfaces,
- protects from oxidization and corrosion,
- dissipate heat from surfaces,
- transport of contaminants to filters,
- power transmission.

During the exploitation of engine lubricants degrade due of oxidation and high temperature, due contamination by combustion products, by solid particles such as dust, outer contaminants, abrasive metals, due contamination by water and a cooling liquid.

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Analytical testing of lubricating oils is an efficient cost-effective tool commonly used to track fluid degradation and assess operating conditions of mechanical equipment. The results when properly interpreted can be useful not only for optimalization of the change interval of lubricant but so for the detection of mechanical faults in critical equipment before equipment failure.

For purposes of evaluation of quality parameters of the lubricant being used, analysts use instrumental methods such as infrared spectrometry with Fourier transformation (FTIR spectrometry) (3,4,5) in combination with chemometrical software (6,7), atomic emission and absorption spectrometry (8,9), electrochemical methods (10), particles analysis using a particles counter (11,12,13), ferrography (14) in combination with scanning electron microscope (14,15) etc.

Kumbár et al. say (16) that the current evaluation of the quality of automotive engine oil can be sufficiently expressed by dynamic viscosity oils, the analysis of wear metals by emission spectrometry and detection and monitoring of the quantity, type and size of wear debris by analyzer of particles.

1. MATERIALS AND METHODS

Through analysis of motor oil samples and assessing their qualitative parameters it is possible to determine its current quality, estimate remaining service life and determine a mode of the lubricated system wear. The aim of analyses of engine oils operated in buses was to judge whether of the setting of intervals of exchange was optimum. In this paper are presented results of analysis engine oil Urania FE 5W/30 that was operated in IrisBus Citelis 12 M - no. 673 (Fig. 1). The complete results are listed in (17).

Source: authors

Fig. 1 - Bus IrisBus Citelis 12M – no. 673

1.1 Infrared spectrometry with Fourier transformation

Infrared spectrometry with Fourier transformation (FTIR spectrometry) is optical non-destructive analytical method, which is providing quick and complex information about state of used lubricant. One of the FTIR spectrometry advantages in comparison to the classical methods, the contamination by foreign substances does not occur. It is also possible to discover the change of sample quality caused by mixing with another oil type or another working liquid, or such fact exclude (18). They are devices working on emission interference principle, which in comparison with dispersion devices measuring the interferogram of emission modulated beam after the transit through the sample. These devices are requiring application of Fourier mathematical method (cosines) transformation, in order to get classical spectral record (19).

$$I(d) = \int_{-\infty}^{\infty} I(\tilde{\nu})\cos(2\pi d\,\tilde{\nu})\,d\tilde{\nu}$$

I – emission intensity, d – way difference of patterned rays, $\tilde{\nu}$ - wave number (1/λ)

One of the methods ascertaining the properties changes of worn or otherwise devalued lubrication oil, fuel or another mixture by help of FTIR spectrometry it is a technique of used and new liquid spectrums subtraction (18). The record of spectrum is lasting 30 till 90 s provides information about composition and amount of impurities including water, penetration of fumes around the pistons (the oil includes carbon and nitridation products), penetration of cooling mediums (ethylenglycol), unburned fuel as well about the degradation caused by nitridation, oxidation and sulphatizing (20).

Infrared spectra were recorded on a Nicolet IS10 spectrometer (Thermo Scientific) in the spectral range of 650–4000 cm-1, with the resolution of 4 cm-1 and with the scan number 64 by means of the ATR technique (ZnSe crystal).

1.2 Atomic emission spectrometry

AES is the method that uses arc or spark sources to get the oil sample into the gaseous state and atomize it. As a result of atomic collisions or energy quantum absorption, the electrons of individual atoms are transiting from the ground state to the excited state. During the transition back to the ground state, atoms emit energy that equals the proportion of the energy levels in question in the form of luminous energy. The wavelength of light value is specific for each element (20). Tribotechnical diagnostics use the methods of AES to determine the degree of wear of friction pairs, the concentration of additives in a lubricant and the concentration of contaminants (21, 22, 23).

Chosen abrasion metals and contaminants were evaluated on spectrometer Spectroil Q100 (Spectro Inc., USA).

1.3 Particle counters

One of recently developed tools working on principle of particle counter in combination with particles shape analyzator is Laser Net Fines (LNF) designed by company Lockheed Martin in cooperation with Naval Research Laboratory and Office of Naval Research. LNF is classifier of particle shape, which is performing the analysis of particles larger then 4 μm by usage of laser and advanced software of image analysis. Images silhouettes of analyzed particles pictures are automatically divided into six categories:

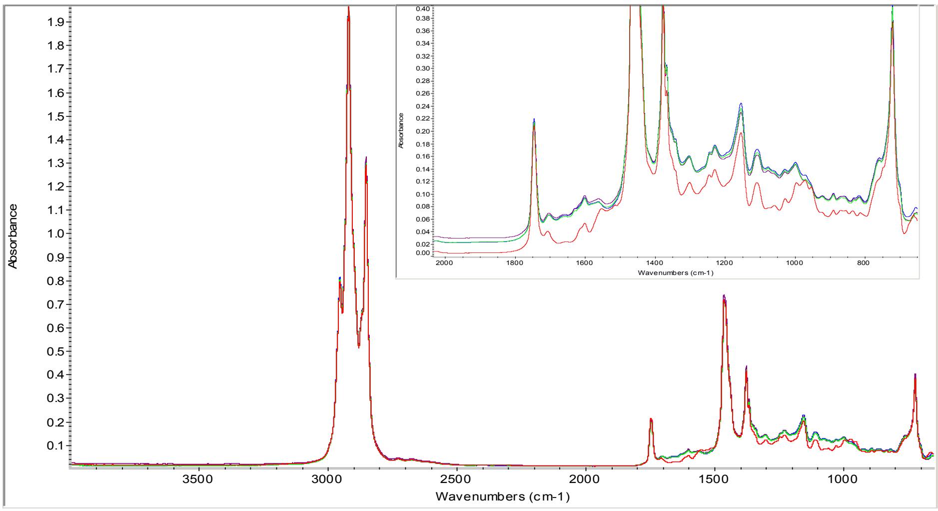
- particles of abrasive wear
- particles of emergency wear
- particles of fatigue wear
- non ferrous particles
- fibres
- water drops.

The information about captured particles are used at evaluation of present wear state of given system and they can be directly observed on monitor of LNF (24).

The evaluation of the wear mode of the most exposed friction surfaces of the engine was realized by the particle analyzer LNF Q200 Laser Net Fines (Spectro Inc., USA).

2. EXPERIMENTAL RESULTS

FTIR spectrometry (Fig. 2) proved significant exhaustion of the basic anti-abrasion and anti-oxidizing additive which is indicated by the reduction of the primary band in the area of 1 040–930 cm^{-1} and the secondary band with the band peak in the area of 660 cm^{-1} (P=S connection) for most oil fills as early as about halfway through the interval of exchange.



— new engine oil Urania FE 5W/30

— worn-out oil of the sample no. 1 (mileage of 18 518 km)

— worn-out oil of the sample no. 2 (mileage of 28 427 km)

— worn-out oil of the sample no. 3 (mileage of 40 243 km)

Source: authors

Fig. 2 - Spectra of operated oil Urania FE 5W/40 fills in bus 673 after continuous sampling

In all worn-out oil fills, pervasion of fuel into the engine oil (growth of the band with the peak in the area of 816 cm^{-1} and 760 cm^{-1}) was detected.

In the case of bus no. 673 which has to comply to the EURO 4 emission standard, FTIR spectrometry did not detect the band in the area of 1 650–1 600 cm^{-1} pertaining to organic nitrates that result from the action of nitrogen acids on the oil. The amount of NOx in the exhaust fumes is reduced using selective catalytic reduction (SCR) for this bus. SCR catalyzer reduces the content of nitrogen oxides in exhaust fumes effectively by reducing them using the urea solution to inertial nitrogen.

Practical application of the TTD instrumental methods on oil samples taken from buses proved that the generally recommended boundary values of abrasion metal concentration are not always sufficient to judge the course of wear of the engine, due to the fact that each engine is specific and it is operated in different conditions. Another reason is the fact that AES is not sensitive enough for detecting the particles larger than 5 µm. In order to judge the course of wear of the engine, it is also to have data about the size-related composition and distribution of abrasion particles available; this can be achieved by analyzing the particles using a laser analyzer.

However, it is also necessary to take the time intervals of sampling, re-filling the oil during operation and the efficiency of its filtering into consideration when interpreting the results of particle analysis.

CONCLUSION

Maintenance strategy based on the state defines the philosophy of a proactive maintenance which should be the real basis for the oil analysis program.

The method of FTIR spectrometry was used for monitoring the chemical degradation of the oil Urania FE 5W/30 used in IrisBus Citelis 12 M. The course and amount of wear of particles lubricated with the respective lubricant was monitored using another group of methods that are suitable for determining the concentration of abrasion metals, for describing their morphology and classification according to their size, and also for determining e.g. the contaminants from outer environment (this applies mostly to emission spectrometry and laser counters of particles).

For the results of particles analysis on a laser analyzer, it is necessary to take the limitations due to its nature, i.e. automated image analysis using artificial intelligence, into account.

At the same time, the results of all analyses need to be evaluated for monitored vehicles from the trend point of view, i.e. to monitor the changes of analytic signals for samples taken in defined kilometrical or time intervals (regular if possible).

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