# MONITORING TECHNICAL CONDITION OF ENGINE BASED ON THE RESULTS OF DIAGNOSTICS TRIBOTECHNICAL

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***Abstract:*** *The article deals with monitoring of chemical elements during lifetime of military vehicles engine oil. Tribotechnical diagnosis is non-destructive and non-dismantling diagnostic method used lubricating oil as a source of information about the processes and changes in the mechanical systems to which it is applied. The paper deals with mathematical processing, tracking and analyzing data obtained from measurement tribo - diagnostics. For the analysis were used following methods AES and FTIR to monitor chemical elements, additives and contamination in engine oil. The increase in the metals and reduce the amount of additives were specially observed. The results were modelled using mathematical models to the value of the correlation coefficient R. The models can be used to predict the engine oil in the same or similar aggregates petrol engines.*

**Keywords**: TRIBODIAGNOSTIC, ENGINE OIL, WEAR, SPECTROMETRY, LIFETIME

## 1. Introduction

Traditional reputable methods and special tribodiagnostic methods are used for monitoring the operating degradation of oils. Determining wear of mechanical systems lubricated by oil is based on knowledge, that oil shows a certain percentage of foreign matter after some operating time. Especially metallic abrasive wear (wear particles), that are dispersed in oil and that after the quantification by some suitable method allows indirect monitoring of mechanical changes in the system that uses the oil. It is then possible to draw specific conclusions based on the determined amount of metallic abrasive wear, growth rate, shape, morphology, size and material composition. If the growth and other parameters are in accordance with nominal values stated for the given mechanical system, it is possible to legitimately deduce normal wear progress without an increased risk of system failure. An abnormal or sudden growth of metallic particles, or their size, indicates an exceptional process. From the size, shape, velocity of growth and other parameters it is possible to deduce the failure severity and necessity to take remedial measures. Knowing the material of all system parts lubricated and rinsed with oil, then according to the metallic abrasive wear type, it is possible to determine and localize the frictional pair with the rapid increase of degrading wear. If it is not possible to localize the position of the increased abrasive wear by this method, then some other technical diagnostics suitable for failure localization should be applied.

The effective tool to monitoring engine condition is analysing of engine oil. With increasing number of taken samples of engine oil increase the accuracy of analyses. The main emphasis is placed to the sampling apparatus – extraction injection, containers, etc. Selection of sampling point and interval of sampling is very important too. This problematic is describes in publication [13].

Extended lifetime of engine oils and downsizing volume of cylinders (with increasing power) are a new trend in these times. The lifetime extension is tempting for customer but for tribotechnic there are the problems. There are no problems for kinematic viscosity, density, and shear stress of engine oils but in used engine oils there are many of metal particles and other contaminants, which pile up in engine oil during lifetime. It can cause malfunction of the engine or even crash the entire system. All of the friction places are made from several metals. The most of them there are treated iron containing other metals, aluminium and copper components, some portion coated with a surface layer of another metal in order to increase the surface hardness and improve sliding properties, improved corrosion protection, etc. Therefore, we must also interested in other metals (except iron only), such as aluminium, copper, chromium, lead, tin, nickel, silver, etc. [3,5].

The other chemical elements, which we must monitoring in engine oil, these are chemical elements contained in oil additives. These are detergents, dispersants, friction modifiers, viscosity modifiers, anti-freeze agents, antioxidants, substances affecting the freezing point, anti-abrasion additives, lubricating ingredients and some others. In most cases these are the elements molybdenum, phosphorus, boron, calcium, zinc, magnesium, etc. Similar theses have been stated in publications [8,9,12].

**Oil analysis methods:**

**Atomic emission spectrometry (AES)** is a 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 [4].

**Fourier transform infrared spectroscopy (FTIR)** is an analytical method designed primarily for identification and structural characterization of particularly organic compounds. Infrared spectrometry measures the absorption of infrared radiation of different wavelength by the analyzed material. The analytical output is the infrared-spectrum that is the graphic representation of energy dependence functions on wavelength of the incident radiation. During the Fourier transform infrared spectroscopy the interferometrically acquired signal is transformed by the Fourier transformation to the infra-red spectrum [4].

## 2. Objects of diagnostics and diagnostics methods

The passenger car Renault Scenic I with gasoline engine has been used. This car have gasoline engine with 1,600 cm3 cylinders capacity and the power 79 kW. The year of made is 1999.

***Table 1:*** *Intervals of collect samples of engine used oil*

| Number of sample | Date of sample taken | Raid of oil, km | Raid of car, km |
|---|---|---|---|
| 1 | 3. 3. 2012 | 0 | 171,790 |
| 2 | 4. 3. 2012 | 20 | 171,810 |
| 3 | 16. 3. 2012 | 1,737 | 173,527 |
| 4 | 28. 3. 2012 | 3,097 | 174,887 |
| 5 | 7. 4. 2012 | 4,462 | 176,252 |
| 6 | 23. 4. 2012 | 6,053 | 177,843 |
| 7 | 9. 5. 2012 | 7,550 | 179,340 |
| 8 | 28. 5. 2012 | 9,104 | 180,894 |
| 9 | 13. 6. 2012 | 11,027 | 182,817 |
| 10 | 27. 6. 2012 | 12,079 | 183,869 |
| 11 | 12. 7. 2012 | 13,815 | 185,605 |
| 12 | 25. 7. 2012 | 15,108 | 186,898 |

Commercially available automotive engine oil Castrol Magnatec 10W-40 (ACEA A3/B3) has been used. The lifetime interval of this engine oil is 15,000 km (according to the manufacturer's recommendations). The samples of used engine oil have been always taken after 1/10 of lifetime interval of engine oil – thus means 1,500 km. The season was spring and summer. The exact intervals of samples taken are reported in Table. 1.

For a more accurate evaluation of the chemical composition measurements have been samples of used engine oils always compared with the results of samples of new (unused) engine oil.

**Diagnostics methods**

With the chemical analyses it has been founding metals and additives in the new and used engine oils.

Determining the chemical composition of oils has been measured using Spectro Q100, which is a completely solid state spectrometer, specifically designed for the analysis of oil samples. With this spectrometer we can measure trace levels of elements dissolved or deposited as fine particles in mineral or synthetic oil-based products using long established and reliable technique with rotating disk electrode. The device meets the requirements of ASTM D6595 standard method for the determination of wear metals and contaminants in used lubricating oils and hydraulic mixtures. Increase metals content and decrease additives content have been modeled using linear function as in publication [6].

Determining the oil degradation and contamination of oils has been measured using Spectro FT-IR Oil Alpha Analyzer is specifically designed for the molecular analysis of lubricating oil to determine oil degradation and contamination. It is used for predictive maintenance programs according to JOAP, ASTM E2412 and DIN standards for the rapid determination of oxidation, nitration, sulfation, water, coolant, fuel dilution, soot, wear additive depletion and synthetic lubricant breakdown in used lubricating oils.

## *3. Oil field data assessment*

By the spectrometry have been determined the chemical composition of samples of the new and used engine oil. The samples of used engine oil have been compared with samples of new engine oil same specification. It is important to the finding of the on-going state of degradation [10].

Determining the engine oil degradation oils has been measured using FTIR methods. It is used for determination wear additive depletion in used lubricating oils. On the Fig. 1 ares showed the difference between new and used motor oil. The difference is evident in the decline belt wavenumber of 1025 - 960 cm $^{-1}$, which displays anti-wear additive (ZDDP).

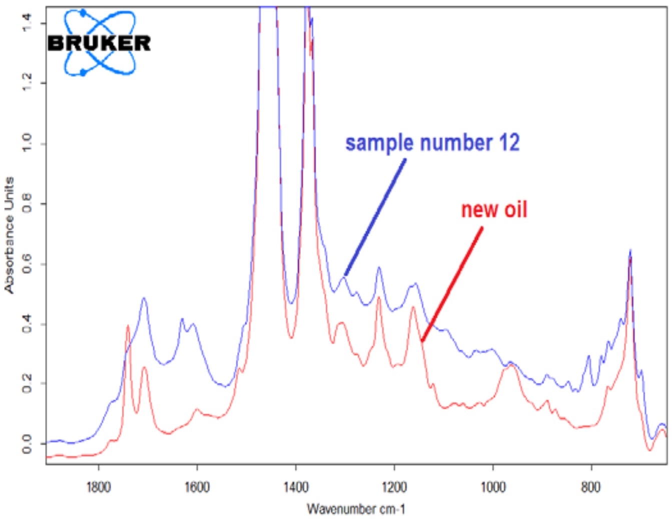


***Fig. 1*** *The resulting infrared spectra for new and used oil*

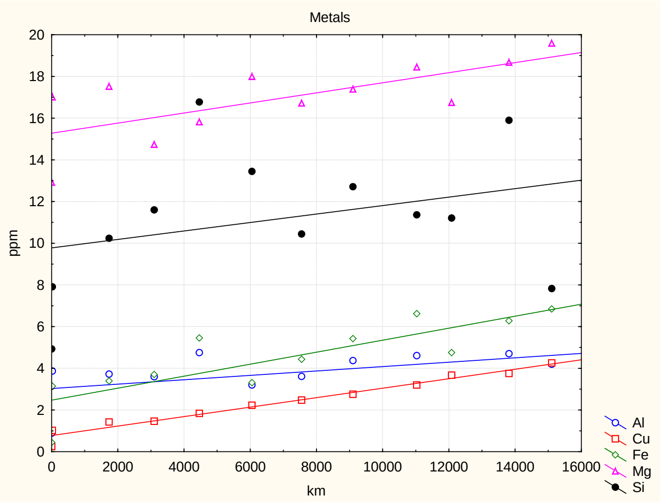


***Fig. 2*** *Increase contents of metals in engine oil*

On the Fig. 3 are showed decreases of some chemical elements using as oil additives. Manganic (Mn) and molybdenum (Mo) decrease slowly with raid but boron (B) decreases quickly with raid. Boron contains in anticorrosion additives.

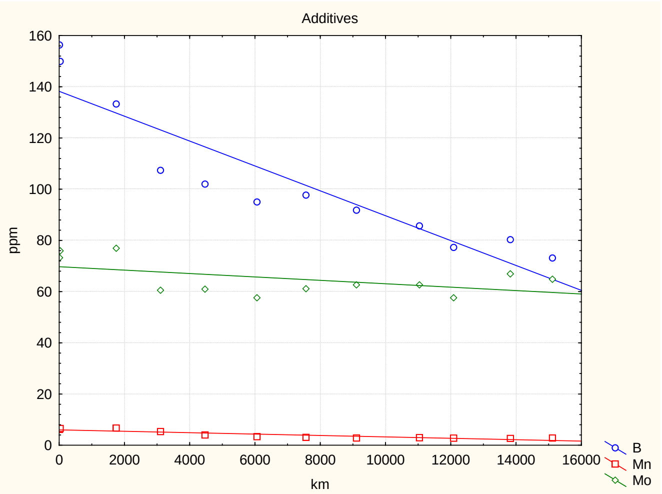


Fig. 3 **Decrease contents of additives in engine oil**

On the Fig. 4 are showed elements phosphorus (P) and zinc (Zn). Phosphorus is usually contained in oil additives and zinc is usually used as construction material of engine.

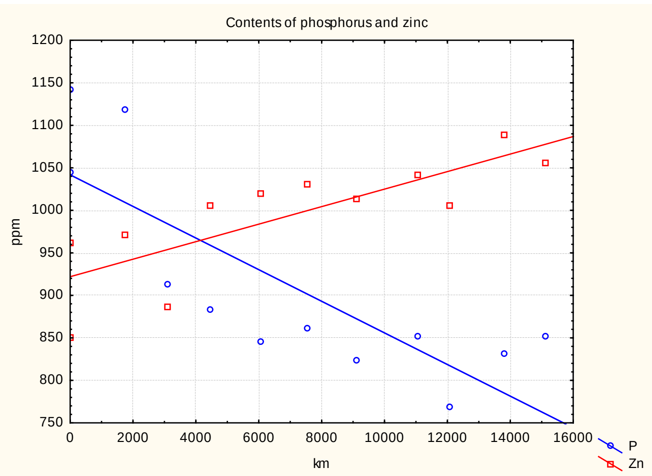


***Fig. 4*** *Contents of P and Zn*

To the modelling increasing and decreasing of metal and chemical elements has been used linear function with general formula:

$$y(x) = A + k.x, \tag{1}$$

to calculate for example iron (Fe) state:

contain of $Fe = 2,4714 + 0,0003 \,.\, raid$ [ ppm; km ] (2)

where we must respect the lifetime of engine oil 15,000 km, respective and maximal 30,000 km.

Correlation coefficients R achieve high values from the 0.79 to the 0.98. Similar values of correlation coefficient achieve authors in publications [1,11].

In the Tab. 2 are showed constant values A and k for all of used chemical elements.

Table 2: *Constant values A and k*

| Chemical elements | Constant **A** | Constant **k** |
|---|---|---|
| **Al** | 3.0318 | 0.0001 |
| **Cu** | 0.7738 | 0.0002 |
| **Fe** | 2.4714 | 0.0003 |
| **Mg** | 15.2793 | 0.0002 |
| **Si** | 9.7779 | 0.0002 |
| **B** | 138.0036 | –0.0049 |
| **Mn** | 5.8424 | –0.0003 |
| **Mo** | 69.5518 | –0.0007 |
| **P** | 1041.6257 | –0.0186 |
| **Zn** | 922.0322 | 0.0103 |

## 5. Conclusions

In this part of the paper we can state that use method (spectrometry) is as one of the basic oil analyses very suitable. The suitability rises when the samples of used engine oil are compared with the sample of new (unused) engine oil with same specification. Using spectrometry we have determined chemical composition of all samples of engine oil. We have also quantified individual chemical elements in the new and used engine oil. With graphs we can see increasing trends polluting elements (metals) and decreasing trends of oil additives (detergents, dispersants, friction modifiers, viscosity modifiers, anti-freeze agents, antioxidants, substances affecting the freezing point, anti-abrasion additives, lubricating additives and some other). All trends have been modeled using linear function. Linear function is basic mathematical model, which we can use. But linear function is very accurate, if we use it properly. Coefficients of correlation R have achieved high values – from the 0.79 to the 0.98. Created mathematical models can be used to prediction changes in lifetime of engine oil fill in same or similar petrol engine.

The aim of the paper is to shed light on the area of tribodiagnostics including the methods which are applicable and suitable for oil analysis. The data regarding lubrication fluid which is available due to performed analyses is a good source of information when considering the cost savings provided the oil is changed systematically. It would be also good to see the results of the analysis in a broader context as an interesting reflection of an actual state of a technical object from where the oil was taken. When taking into account the results of the tribological analysis, the cost savings might be manifested as the extension of oil changes time and relating maintenance costs and downtime resulting from object unavailability by extraneous causes. Since there is a wide spectrum of suitable methods while analyzing an immediate state and prognosis (PHM – Prognostics and Health Monitoring), and because the area falls very deeply into interdisciplinary studies, the specification of relevant dependencies of the analysis results on a real technical state is not at all an easy task to do.

## 6. Literature

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