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THE USE OF SPECTROMETRIC DIAGNOSTICS IN IDENTIFICATION OF THE TECHNICAL CONDITION OF TRIBOLOGICAL SYSTEMS

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Abstract

The paper presents, as an effect of the analysis of investigation results, a possibility of using the spectrometric diagnostics in the tribological system technical condition supervision arrangement.

A model, based on the emission of solid particles in tribological system operation, allows to identify the system technical condition. After the analysis of tests carried out with the use of that model, it has been found that the content of elementary substances in the lubricating oil may be considered a tribological system condition parameter.

Key words: tribological system, spectrometer, correlation

1. Introduction

Correct running of an internal combustion engine requires the knowledge of the current technical condition of all its tribological systems. That allows to take proper decisions on further running, shut-down, repair or other appropriate actions. Fig. 1 below shows that the pre-failure period begins at moment I, then symptoms appear that an admissible value [1] of the engine tribological system has been exceeded.

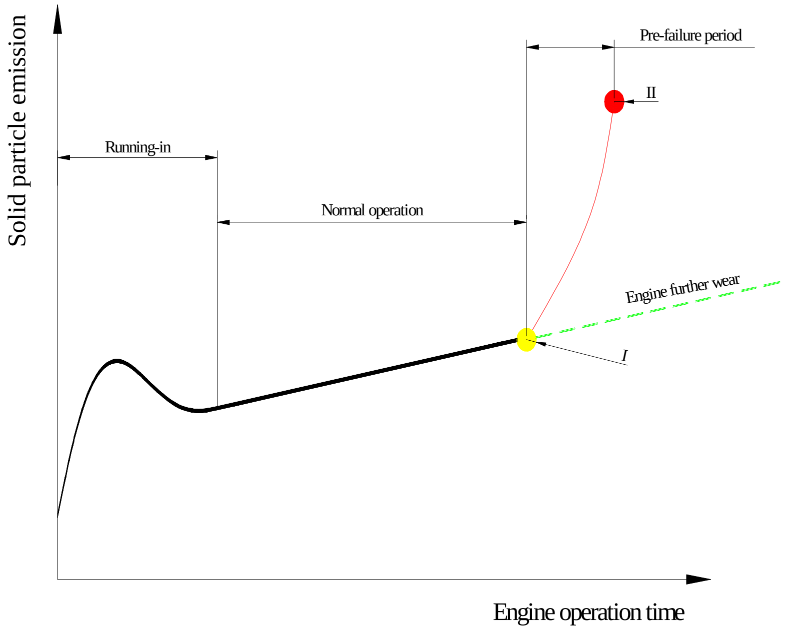

Fig.1. Changes of the wear product emission [4], where:
I – excessive wear (problem appears), II – failure (engine shut-down)

The engine may continue to perform the functions but its technical and operational properties do not meet the requirements (e.g. excessive wear of piston rings causes increased fuel consumption). This type of a symptom may be e.g. an increased content of metals in the lubricating oil. An effect of the missed or disregarded pre-failure period symptoms is cumulation of changes in the engine technical condition and ensuing engine failure.

Further wear of the engine, if the failure has been prevented, is marked with broken line.

The lubricating oil, as one of the tribological system elements, is also subject to qualitative changes and it reflects the technical condition of tribological system. Taking that into account, a model has been developed allowing to identify the tribological system technical condition from the spectrometric diagnostics.

The work is aimed at investigating to what extent the content of elementary substances in the lubricating oil may be treated as a parameter evaluating the technical condition of a tribological system.

2. Methodology of investigations

The content of elementary substances, such as iron (Fe), copper (Cu), zinc (Zn), nickel (Ni) and calcium (Ca), in the lubricating oil is determined by the X-ray fluorescence method on a Philips X-Met920 spectrometer.

The investigated sample is irradiated by primary rays (from an X-ray tube). Atoms of the sample absorb photons, disposing of electrons from the internal orbitals. A "vacuum" that is created in that way will be filled by transferring another electron from an external orbital and a difference of energy between the two orbitals will cause emission of fluorescent X-radiation.

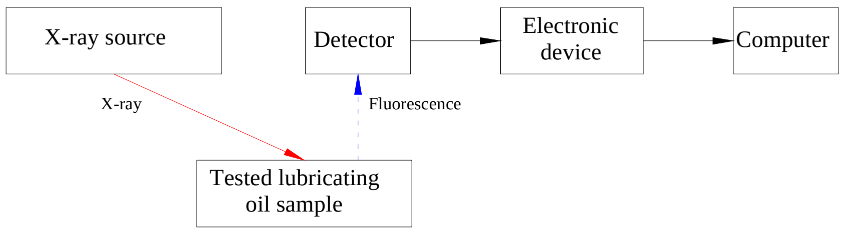

Fig. 2. Schematic diagram of the XRF spectrometer

The XRF method is based on the phenomenon that each elementary substance contained in the tested sample emits, under the X-ray excitation, a characteristic spectrum subject to a qualitative and quantitative analysis.

The investigation model allowing to use the spectrometric diagnostics for identification of the technical condition of a tribological system analyses results of two stages of investigations.

The first stage consists in testing the content of elementary substances in an oil sample taken from a running engine or immediately after the engine stoppage, before the filter (e.g. the LUBIANA [4] system).

Next, a test is carried out on a T-02 four-ball extreme pressure tester (made by ITeE in Radom [3]), with linear increase of the friction node load in any temperature range. The friction node consisted of dia. 12.7 mm ball bearing balls made from the LH15 steel (an iron Fe alloy with average content of 1% C, 0.02% S, 0.3% Ni, 0.3% Cu) in the accuracy class 16 in accordance with the PN-83/M-86452 standard, lubricated with the oil tested on the spectrometer at the first stage. The friction node linear increase of load to 7.4 kN led to the ball seizure, which caused change of the elementary substance content in the lubricating oil. After completion of each test (lasting 18 seconds) the lubricating oil was poured from the friction node pocket to the spectrometer sampler in order to check the solid particle emission.

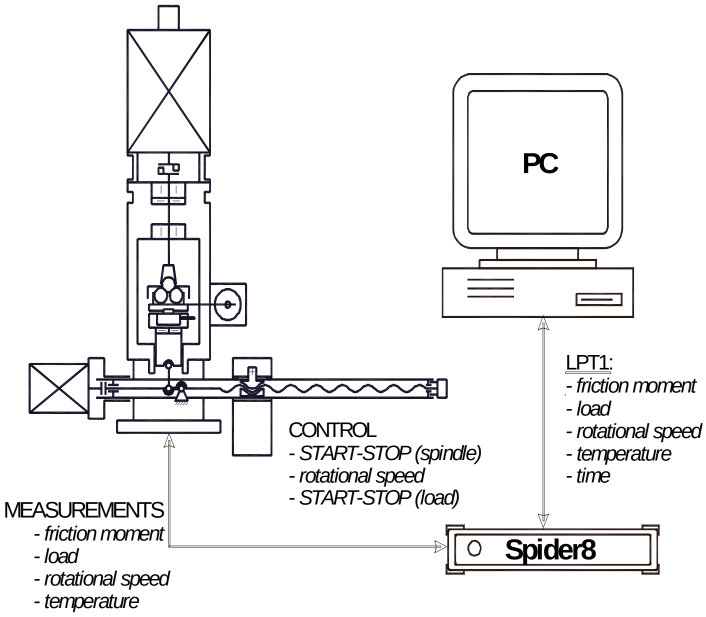

Fig. 3. Schematic diagram of the T-02 [3] four-ball extreme pressure tester measurement and control system

In the second stage the content of elementary substances, such as iron (Fe), copper (Cu), zinc (Zn), nickel (Ni) and calcium (Ca), in the lubricating oil is determined again on a Philips X-Met920 spectrometer.

3. Analysis of the investigation results

Analysis of the investigation results was carried out on the Daewoo API SJ 5W-30 lubricating oil samples taken from a LANOS 1,5 DOHC engine in the 2005 to 2008 operation period.

3.1 First stage of investigations

From the spectrometer measurement results of the lubricating oil samples (Table 1), an analysis (Fig. 4) was performed in order to determine which initial parameter may be considered a diagnostic parameter of the tribological system technical condition.

Table 1. Elementary substance content

Type of lubricating oil Daewoo API SJ 5W-30	Initial parameters - elementary substance content [ppm]				
	IRON	ZINC	COPPER	NICKEL	CALCIUM
Clean - unused	61,2 ± 1,5	514,7 ± 8,8	863 ± 11,9	647,1 ± 11,4	3788,7 ± 191,8
After one year of use from 2005 to 2006	87,0 ± 2,6	453,7 ± 8,3	811 ± 72,3	577 ± 10,8	2807,1 ± 168,8
After one year of use from 2006 to 2007	92,4 ± 2,7	491,7 ± 8,6	828 ± 58,5	647,6 ± 11,4	3491,7 ± 185,5
After one year of use from 2007 to 2008	116 ± 3,0	536,7 ± 9	925 ± 12,3	692,3 ± 11,8	3366,1 ± 182,7

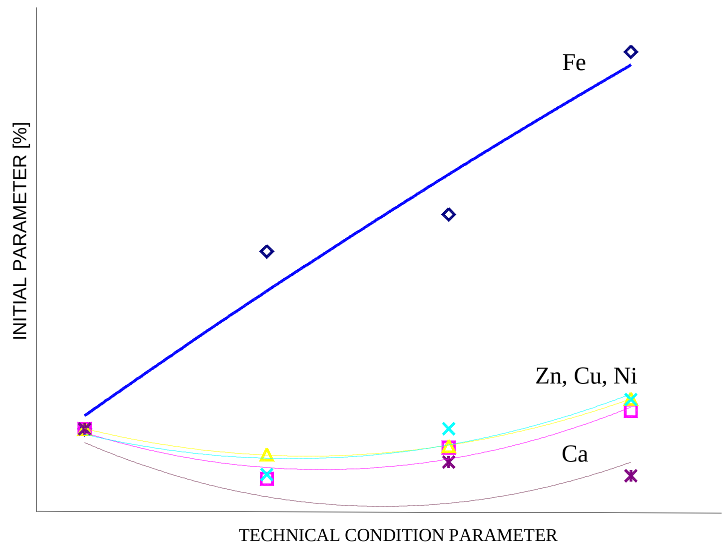

Fig. 4. Graphical illustration of variants of the technical condition [2]

An initial parameter (e.g. content of an elementary substance in the lubricating oil) may be considered a tribological system technical condition diagnostic parameter if it meets the following requirements:

- uniqueness (i.e. each value of the technical condition parameter corresponds with only one determined amount of the elementary substance),
- sufficient range of the parameter values (i.e. better is the initial parameter with greater change of value for a given change of the technical condition parameter),
- availability (easy measurement of the elementary substance content).

Fig. 4, presenting the first stage measurement analysis, indicates that the most unique parameter, with the widest range of values, is the content of iron. The availability requirement will be verified in the analysis of the second stage measurements.

3.2 Second stage of investigations

After the test of oil samples (at 80^{o}C - oil temperature during the engine run) in the T-02 four-ball extreme pressure tester, the elementary substance content was measured (Table II). Then an analysis of initial parameters was performed in connection with the T-02 apparatus ball seizure (Fig. 5).

Table II. Elementary substance content

Type of lubricating oil Daewoo API SJ 5W-30	Elementary substance content [ppm]				
	IRON	ZINC	COPPER	NICKEL	CALCIUM
Clean - unused	102 ± 2,8	519,8 ± 8,9	900 ± 12,1	667,2 ± 11,6	3666,9 ± 189,6
After one year of use from 2005 to 2006	147 ± 3,3	473,4 ± 8,5	805 ± 11,5	599,6 ± 11	3150,5 ± 178,1
After one year of use from 2006 to 2007	161 ± 3,4	505 ± 8,7	891 ± 12,6	670,3 ± 11,6	3308,3 ± 181,5

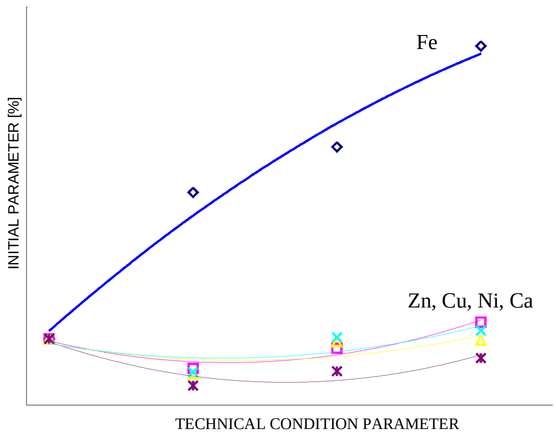

Fig. 5. Graphical illustration of variants of the technical condition [2]

An additional conclusion drawn from the second stage measurement analysis (Fig. 5) is that the iron content in lubricating oil is the easiest available initial parameter (the ball wear clearly increases the iron content in the lubricating oil).

3.3 Identification of the tribological system technical condition

The graphical illustrations (Fig. 4 and 5) indicate that the iron content may be considered a diagnostic parameter of any tribological system technical condition. Additionally, worth mentioning is the high value of the correlation coefficient (Table III) between the seizure load P_t (determined in the four-ball extereme pressure tester - Fig. 6) and the iron emission during the ball seizure.

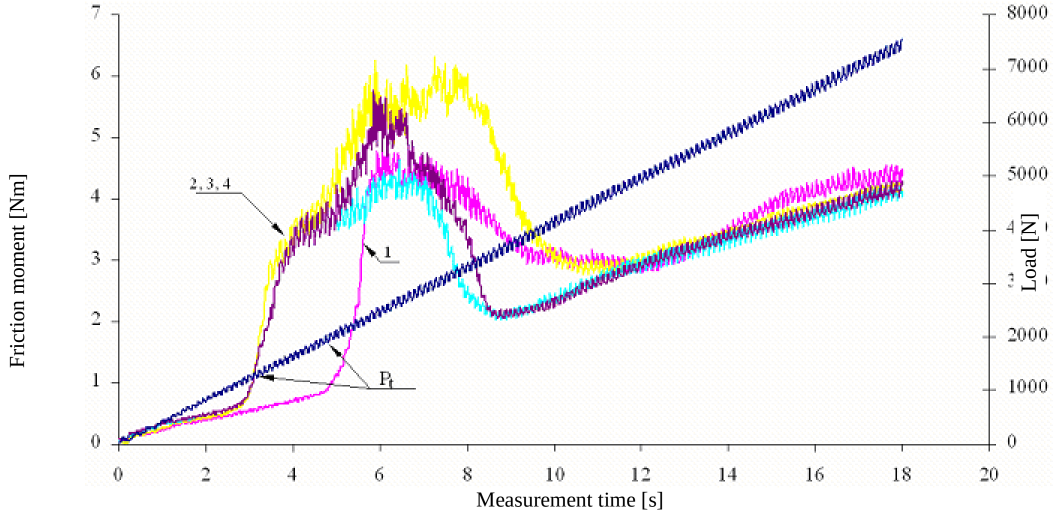

Fig. 6. Friction moment curves obtained in the constant load increase conditions, where: 1- clean unused oil, 2 – oil after one year of use from 2005 to 2006, 3 – oil after one year of use from 2006 to 2007, 4 – oil after one year of use from 2007 to 2008, P_t – seizing load

Table III. Correlation coefficient

P_t [N]	Fe[ppm]	Correlation coefficient r
2119,2	102 - 61,2 = 40,8	-0,92456
1350	147 - 87 = 60	
1305	161 - 92,4 = 68,6	
1297	192 - 116 = 76	

The high value of the correlation coefficient of the lubricating oil random samples from normal distribution sets allowed also to check whether there was correlation of those two parameters in the set (i.e. the lubricating oil installation) where the random sample had been taken from. Checked is then the zero hypothesis: H_O: $\rho = 0$ assuming that there is no correlation in the set between those two parameters.

The t Student test is used for the purpose [2]:

$$t = \frac{r}{\sqrt{1-r^2}} \cdot \sqrt{n-2} = \frac{0{,}92456}{\sqrt{1-(0{,}92456)^2}} \cdot \sqrt{4-2} = 4{,}85281$$

where: r – correlation coefficient calculated from the sample data;
n – sample size.

With the significance level 0.05 and n-2 = 2 degrees of freedom, the value read out from the t Student distribution: $t_{0.05} = 4.303 < t = 4.85281$ – therefore the zero hypothesis may be rejected and conclusion may be drawn that correlation exists in the whole lubricating oil set between the seizure load and the iron content.

4. Final remarks and conclusions

- The presented investigation results have shown that emission of elementary substances may be considered a symptom of wear of the investigated tribological systems.
- The quantity of iron in the lubricating oil has an impact on the seizure load.
- The presented identification model of a tribological system technical condition may be included in a tribological system supervision arrangement, which is confirmed by rejection of the zero hypothesis H_O.
- The applied measurement method of the iron content in lubricating oil may be used to determine the oil temperature, which may prove useful for the EA registration and analysis in investigating the surface and the lubricating oil interaction.
- The scope of measurements performed with the apparatus may be extended by:
    - change of the bearing ball material (now it is the LH15 bearing steel) so that its surface structure is similar to that of the slide bearing liner,
    - wider range of different elementary substances measured in the lubricating oil.

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