



## THE USE OF ACOUSTIC EMISSION FOR ASSESSMENT OF THE OIL LUBRICITY IN A FOUR-BALL TESTER

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### Abstract

*In view of the increased dynamic and temperature load in the compression-ignition engine tribological systems, particular attention is drawn to the problem of such lubrication of the friction nodes that after breaking the boundary layer it could be restored without any wear occurring. Therefore, an idea has been devised of introducing to friction nodes, with the lubrication oils, of new substances (operational preparations) modifying the surface layer of friction elements, creating the so called servo-films as an effect of selective transfer at the extreme loads.*

*The paper presents a method of evaluation, by means of the acoustic emission (AE) symptom, of a lubricating oil, without operational preparations, through creation of the servo-film.*

**Keywords:** *acoustic emission, servo-film, friction node*

### 1. Introduction

An ideal situation in the compression-ignition engine operation would be if tribological systems could work in wear-free friction conditions in the extreme working states.

The lubricating oils used today, in spite of their indispensable advantages (e.g. heat abstraction, friction coefficient reduction etc.), still do not solve the problems of under-lubrication in the extreme load conditions. Therefore, research work is being carried out on the operational preparations [6] facilitating the servo-layer creation in the under-lubricated tribological systems.

The paper draws attention to the fact that compounds with similar properties as the operational preparations are spontaneously created in the lubricating oil during normal work and they can be identified by the acoustic emission parameters. Therefore, an analysis and evaluation of the boundary layer "reconstruction" (i.e. servo-film creation) process was performed based on measurements of the T-02 four-ball tester friction node with piezoelectric gauges connected to it.

### 2. The selective transfer phenomenon

In the development of knowledge on tribological phenomena, worthy of attention is the selective transfer effect creating on the friction faces a thin plastic non-oxidizable film of a specific structure. The selective transfer phenomenon consists in using the electric charge generated in the lubricating oil by friction of displacing surfaces for transporting the particles torn out of those surfaces.

The literature studies [4, 6, 7, 8] indicate two dominating hypotheses explaining the selective transfer mechanism:

1. Mechanism based on microadhesive joining the soft metal particles with the hard metal friction face. In the first stage the created protective film is composed of the soft metal particles. That composition can change when conditions favourable to the selective transfer process occur.
2. Mechanism based on the electro-chemical process of protective film creation. The film contains only one metal added to the lubricating oil in the form of a metallizing admixture. In the case of copper alloys - copper is transferred.

The selective transfer effect in a friction node requires the use of lubricating materials allowing to generate oxide films on the friction faces and also capable of electro-chemical copper decomposition. The copper release and transfer process is an outcome of the reaction of lubricating agent with the friction node surface. The copper and iron ions are then generated "reconstructing" the friction node boundary layer.

The ionic bond is a non-directional bond where electrostatic attraction occurs between ions generated in the total transfer of valence electrons from a less electronegative atom to a more electronegative atom. In effect of the electron transfer, the first atom becomes a positive ion (cation) and the second one a negative ion (anion). The ion generating is connected with the ionization energy, i.e. the energy needed for abstraction of the most loosely bound electron from a single atom. The ionization energy is usually expressed in electron volts ( $1 \text{ eV} = 1.60210 \cdot 10^{-19} \text{ J}$ )[1].

The boundary layer "reconstructing" servo-film is created when a sufficient number of copper ions is generated for the selective transfer process to be started. Therefore, the time needed for generating the sufficient number of copper ions is also a meaningful parameter of the servo-film creation process. Creation process of the servo-film in a friction node may be identified [5] with slide bearing operation and expressed in joule-seconds [J·s].

### 3. Research methodology

The investigations with T-02 four-ball tester were carried out in three variants with the Marinol RG1240 lubricating oil and 8S20UD-H.Cegielski-Sulzer engine, namely:

- fresh oil (not used for lubrication before),
- used oil,
- used oil with 5% content of MDO fuel the engine is fed with.

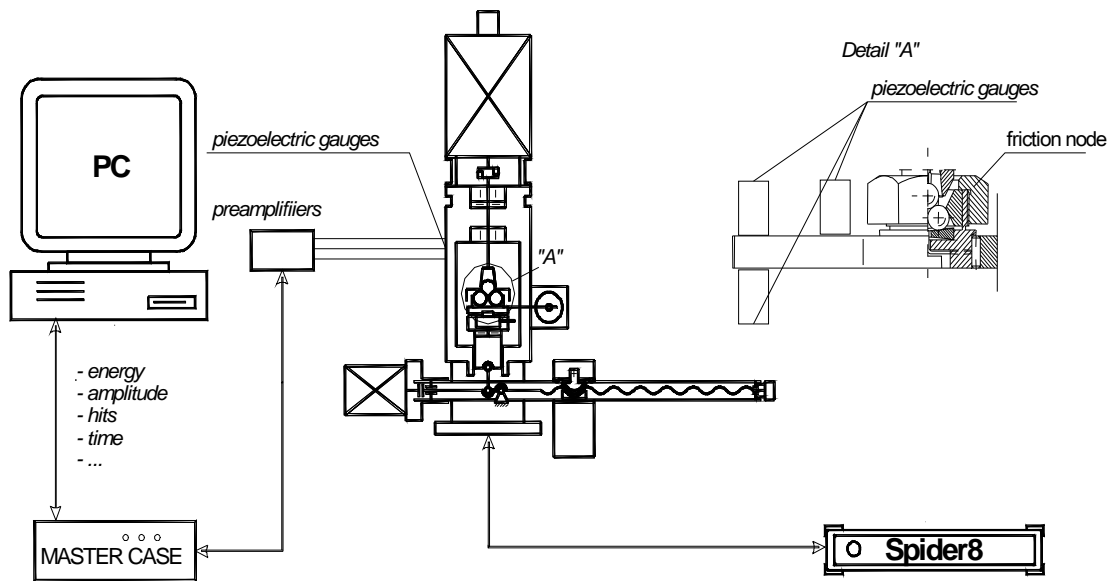
The investigation parameters were the following:

- spindle rotational speed: 1000 rpm
- load increase rate: 409 N/s
- initial load: 0 N
- maximum load: 7400 N

The friction node consisted of bearing balls, 12.7 mm diameter, made from the ŁH15 steel (ferrous alloy with average content of 1% C, 0.02% S, 0.3% Ni, 0.3% Cu), in the accuracy class 16 according to the PN-83/M-86452 standard, submerged in the lubricating oil tested.

Each test in the T-02 four-ball tester was additionally analysed by the acoustic emission gauges of a Vallen AMSY-5 apparatus set (Fig. 1 and 2) [2].

The increased content of copper in the investigated lubricating oil sample of the friction node was measured with a Philips X-Met 920 spectrometer [3].



Schematic diagram of the Vallen-Systeme GmbH

Schematic diagram of the T-02 four-ball tester

Fig.1. Test stand diagram [2]

The acoustic emission phenomenon demonstrates itself by generation and propagation of elastic waves originated in the T-02 four-ball tester friction node during the dynamic processes proceeding in it. The propagating elastic wave is recorded by piezoelectric gauges mounted on the friction node as an acoustic signal (pulse), as shown in the Fig. 2 diagram.

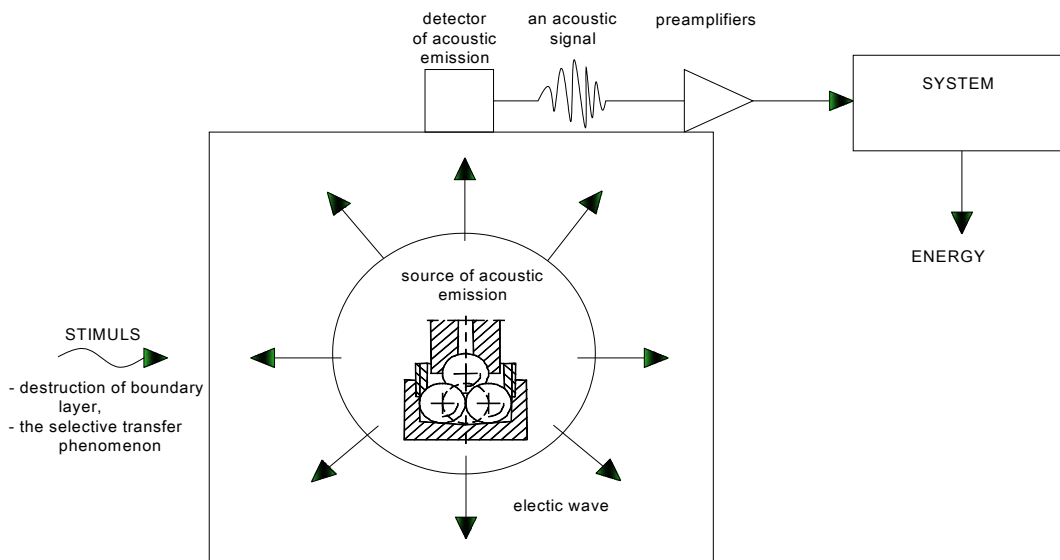


Fig.2. Acoustic emission phenomenon on T-02 four-ball tester friction node

The investigations performed with the T-02 four-ball tester connected with piezoelectric gauges, where the friction node consisted of a set of four steel balls submerged in the tested oil, are aimed at monitoring the boundary layer "reconstruction" process (Fig.3).

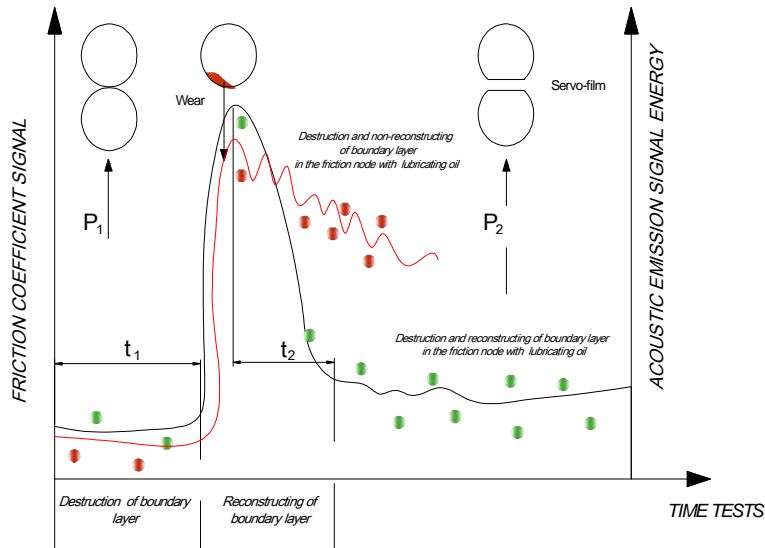


Fig. 3. Destruction and possible reconstruction of boundary layer

where:

- - destruction and non-reconstructing of boundary layer (friction coefficient signal),
- - destruction and non-reconstructing of boundary layer (acoustic emission signal energy),
- - destruction and reconstructing of boundary layer (friction coefficient signal),
- - destruction and reconstructing of boundary layer (acoustic emission signal energy).

#### 4. Analysis of test results

Results of the investigations of physical and chemical properties during the boundary layer "reconstruction" are presented in graphical figures 4 to 7 and in Table 1.

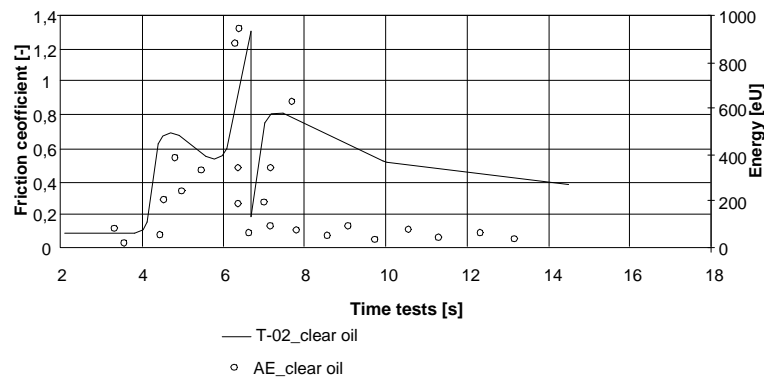


Fig. 4. Destruction and non-reconstructing of boundary layer in the friction node with fresh Marinol RG1240 lubricating oil

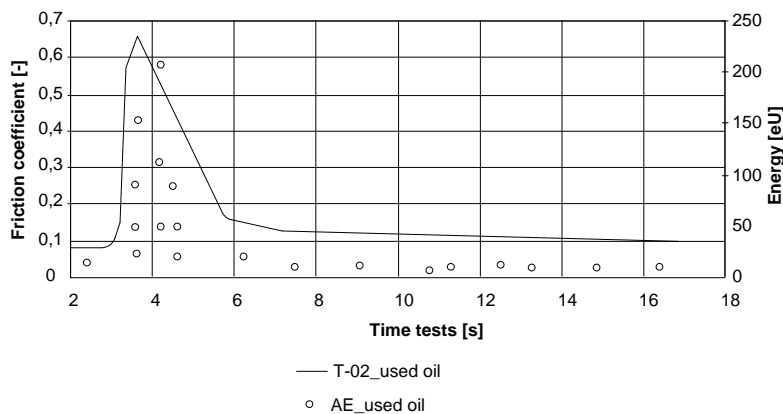


Fig. 5. Destruction and reconstruction of boundary layer in the friction node with used Marinol RG1240 lubricating oil

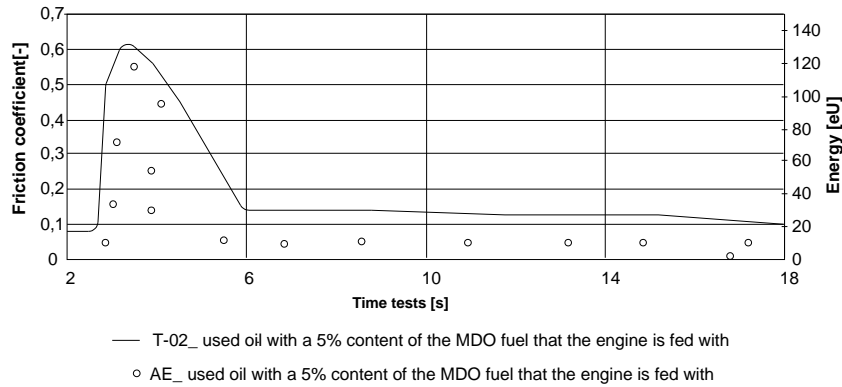


Fig. 5. Destruction and reconstruction of boundary layer in the friction node with used Marinol RG1240 lubricating oil with 5% MDO

Table 1. Results of the investigations of physical and chemical properties during the boundary layer "reconstruction"

Marinol RG1240 lubricating oil	E <sub>1</sub> [eU]	E <sub>2</sub> [eU]	E[%]	Cu <sub>1</sub> [ppm]	Cu <sub>2</sub> [ppm]	ΔCu[ppm]
clear oil	900	450	50	112,44±1,23	121,06±1,237	8,62
used oil	200	12	94	122,44±1,297	143,11±1,27	20,67
used oil with 5% MDO	120	12	90	122,44±1,297	133,00±1,252	10,56

where:

E<sub>1</sub> – acoustic emission signal energy for the boundary layer destruction,

E<sub>2</sub> – acoustic emission signal energy for the boundary layer "reconstruction",

$$E = \frac{E_1 - E_2}{E_1} \cdot 100 - \text{loss of the acoustic emission signal as a fitness for use measure,}$$

Cu<sub>1</sub> – copper content in an oil sample before the friction node test,

Cu<sub>2</sub> – copper content in an oil sample taken after the friction node test.

Small acoustic emission signal loss (E = 50%) shows "non-reconstructing" of the friction node boundary layer, i.e. selective transfer did not occur. Therefore, this acoustic emission signal may be considered a symptom of not full friction node fitness with respect to the extreme loads.

## 5. Acoustic emission as a diagnostic signal

Lubricating oil is a significant element of the compression-ignition engine tribological systems as it contains necessary information for determining diagnostic relations of such systems. Those relations are needed for building a tribological system diagnostic model. Development of such model, useful in practical engine operation, requires reliability of the diagnostics.

The measurement results are a signal, in the form of acoustic emission, containing the status information. It has been demonstrated that there is a possibility of increasing the reliability of diagnostics by using the acoustic emission parameters for determining the servo-film effect.

In the proposed procedure, the servo-film effect is understood as transfer of ionization energy, in the form of work, coming from an extreme load of the friction node in a specified time t and causing "reconstruction" of the boundary layer.

The servo-film effect in the proposed version may be investigated by carrying out precise measurements and then expressed in the form of a number with joule-second as the measurement unit.

## 6. Final remarks and conclusions

The main objective of the work was to present the possibilities of using the acoustic emission

as a diagnostic parameter in the friction node condition determining laboratory test. Generating the copper ions is worthy of attention. Investigating of samples with the X-Met920 spectrometer allowed to conclude that the increase of copper content in the used Marinol RG1240 oil had a positive impact on the servo-film effect. In the copper ion generating process ionization energy is emitted - a component of the acoustic emission energy defining the servo-film effect.

Additionally it was found that during operation some compounds were spontaneously created in the Marinol RG1240 lubricating oil improving its physical and chemical properties. However, the performed measurements did not provide quantitative conclusions on the friction node effects of that phenomenon (equivalent to introducing operational preparations) as no comparative tests were carried out.

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