DIAGNOSIS OF TECHNICAL CONDITION IN DIESEL ENGINE TRIBOLOGY ASSEMBLIES

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Abstract: *Lubrication is the primary activity in prevention maintenance of technical systems and is defined as the application of certain lubricant in order to decrease the force as well as the wear and sliding surface damaging. Sliding surface material which causes these effects represents grease. Even though the lubrication process and grease are defined solely from tribological aspect, their primary role is much more important and diversely expressed in the wide range of technical systems. Each role demands a specific grease and its additives' characteristics. This paper will show the experimental investigation results performed on the gear (dumper trucks' diesel engines) in the ,,Banovići" coal mine, while the laboratory sample examination of grease has been performed in the "Modriča" oil refinery.*

Keywords: TRIBOLOGICAL SYSTEM, TECHNICAL STATE, DIESEL ENGINE

1. INTRODUCTION

The basic function of lubrication oil in tribo-mechanical system is of tribological nature and consists of disuniting the direct impact between contact surfaces which have a relative movement – this is the role of lubrication in the narrow sense. However, grease as an element of a system also has other functions related to protection of elements from other (non- tribological) influences.

Components of a tribomechanical system are exposed to effects of heat generated by friction, but they, in addition, absorb heat that is being produced through processes of internal combustion of fuel or compression of the working medium. Grease exhibits the role of absorbing heat from rotational elements and transferring it onto the bearing box or leading it from the tribomechanical system thanks to continuous movement through the circulatory system of greasing (1).

2. THEORETICAL EXPLORATIONS

The greatest number of machine systems has one or more pairs of elements that are interconnected and in a state of relative movement. The characteristics of these mutual contacts of elements are defined through mutual physical exertion and the shape of of contact surface, type and intensity of relative movement, topography of surfaces in contact, kinds of materials in the contact zone, generated thermal energy, etc. The contact of two elements with a third element that separates them in a smaller or larger manner is called a TRIBOLOGICAL SYSTEM (TS). The internal process in a tribological system is called TRIBOLOGICAL PROCESS (TP), which usually encompasses friction and attrition of contact surfaces (2). Practice in machine and mechanisms exploitation has shown that providing prognoses regarding their spoilage is in an entire string of cases most efficient when based on parameters that directly “bear witness” to processes of fraying – particles that are result of fraying. Through examination of oil sample containing particles that originated from fraying, it is possible to evaluate the condition of TS in early stages of utilization. Generally, the concentration of particles in the sample and their distribution through dimensions exhibits the velocity of fraying and level of scuffing. Equable concentration of minuscule particles fits normal working regime. An abrupt appearance of bigger particles in the oil points to the beginning of process of catastrophic scuffing.

For years, most laboratories that were engaged in analysis of grease from the exploitation process, have been examining certain physical and chemical alterations, such as:

- viscosity on various temperatures,
- temperature of ignition,
- neutralizing number (acidic number),
- fuel contents,
- water contents etc.

Further development of methods expanded those explorations also to:

- determining contamination of grease with metal particles, as well as
- determining only chemical changes in oil, not only qualitatively but also quantitatively.

Today, the most significant are the following methods:

- gas chromatography,
- atomic absorption and emission spectroscopy,
- infrared spectroscopy,
- ultraviolet spectroscopy,
- mass spectroscopy and
- nuclear magnetic resonance.

Among these methods, the most significant are atomic spectroscopy and differential infrared spectrometry, which, combined with membrane filtration offer the greatest number of most reliable data.

3. Experimental research

3.1. Experiment plan

The research was conducted on the surface pit in hard coal mine – Banovići, on dumper trucks: Tereks-MT 3600 B with bearing capacity 1540KN int. mark (5), Mark 36 with bearing capacity 1540KN int. mark (11) and Tereks-MT 3600 B with bearing capacity 1540KN int. mark (4).

The requirements for implementation of the aim were fulfilled as follows:

- technical systems,
- tribological system,
- research parameters,
- temporal interval of oil samples,
- methods of examining oil,
- means-appliances for examination,
- oil examination,
- analysis of acquired research data,
- analysis of measured quantities – comparison with boundary values
- concluding observations.

3.2. Technical systems

In the process of coal exploitation, in hard coal mine – Banovići mining machinery and equipment of great capacities is applied, which results in vast amounts of mined mineral raw materials.

This paper will, due to spatial limitations, represent research results only for dumper Mark-36. In hard coal mine "Banovići" temporal status images are meticulously managed. Temporal status image is the result of working process and processes of conducting maintenance, and represents the elementary basis for research of system efficacy during working process. Analysis of temporal status image of dumper truck Mark-36 has shown that the critical subsystem, from the standpoint of quantity and duration of status "TERMINATED", is in fact the diesel motor. These dumpers have built in diesel motors CUMMINS – KTA 50 C with 1194 (KW) output with 1900 o/min. Experiences with exploitation have proved that newly built motors generally undergo repair after 18.000 – 20.000 motor hours in average. After the general repair is completed, these motors work 7.000 motor hours. The manufacturer gives warranty for one year on a new motor and extended warranty on certain sub-assemblies and elements such as motor block and crankshaft. During warranty period, it is necessary to strictly uphold manufacturer's instruction manuals regarding exploitation and motor maintenance. The manufacturer prescribed manuals for maintaining and monitoring the work of the motor during exploitation. Therefore, according to this manual, oil gets changed after 250 hours of motor work in exploitation. These motors use motor oil 15W-40, which has the characteristics in accordance with those prescribed by the manufacturer. Evaluation of the motor's state in exploitation is conducted through monitoring working parameters, such as: pressure, temperature, number of orbits etc. In order to extend the working life of the motor, that is, to reduce the number and duration of standstill, monitoring working parameters only is not sufficient. It is necessary to include new methods of maintenance, which would reflect maintenance according to status. For this purpose, a new diagnostic method of ascertaining the status of diesels motors was included – procedure of control of fraying and combustion. Practice in exploitation of technical systems has shown that prognosis of their breakdowns in an array of cases is most efficient when based on parameters that are direct 'witnesses' of fraying process – particles that arise through fraying. Examination of oil samples with particles from fraying process enables the assessment of the state of tribological assemblies in the early stages of usage. Generally, the concentration of particles in a sample and their distribution through dimensions points to velocity of fraying and level of wearing. Normal working regime requires a leveled concentration of small particles. Abrupt increase in larger particles in oil points to the beginning of the process of catastrophic fraying.

3.3. Defining tribological systems

Experimental research was conducted in exploitation conditions on sliding bearings (recumbent and volatile) of the crankshaft in diesel motor Cummins KTA50C, which were built in dumper trucks, and they are the subject of this research. Tribological systems, in this concrete case, are consisted of trunnions of reciprocating rod (recumbent – main and volatile), their associated sliding bearings (sleeves – halves) and greasing substance (oil).

3.4. Defining time intervals of oil sampling

Oil sampling during exploitation is the most critical aspect of its analysis, with the aim of acquiring data which serve as basis for diagnosing the status of a lubricated system, from the aspect of state of tribological assemblies, as well as from the aspect of state of lubricating oil. Literature recommends sampling intervals when it comes to lubricating oil. For diesel motor, the recommended interval of sampling is 150 – 500 working hours. These recommendations apply to typical equipment which is used in average conditions. Considering the fact that technical systems which are subject of these experimental research work in difficult conditions (geo-mechanical, temporal, etc.), it is necessary, while determining the dynamics of sampling, to take into account other influential factors.

Those factors refer to various consequences of failure, exploitation conditions from the aspect of working regime and maintenance conditions, age of the system, age of the lubricant, defined tolerance in changing oil and the entire system.

According to manufacturer's recommendations, in Cummins diesel engines oil is changed every 250 motor hours, so this factor should also be included while determining the dynamics of sampling.

Taking into account factors such as: gravity of consequences of failure, exploitation conditions, age of the system and oil change period, for this experimental research the following sampling dynamics was determined – new oil sample is taken, then a sample is taken after 100, 150, 200 and 250 motor hours when oil is changed, after which the procedure is repeated.

3.5. Defining quantity and manner of oil sampling

In order to acquire a representative sample, considering the fact that a non-representative sample inevitably renders all following steps in analysis procedure unsuccessful, results in inaccurate diagnosis of status and presents a basis for reaching inaccurate conclusions and conducting wrong activities in maintenance, it was determined that samples should be taken from three dumper trucks of the same bearing capacities, which work in very similar conditions. Ten samples were taken for every dumper, which means that the procedure was repeated twice, due to limited possibilities in sampling since sampling was conducted in dumper exploitation stage.

During oil sampling (determining location, procedure and sampling instruments), rules described in the theoretical part were complied with.

3.6. Defining methods of oil examination

There is a great number of different tests within oil analysis that are used while assessing status. Tests must cover three

interest areas:
– state of the technical system,
– state of impurities in lubricant and
– state of the lubricant.

The term "oil analysis" has been accepted in the industry and can be understood in a way that the primary area of interest is analysis of state of the lubricant, while in reality, that is in fact monitoring the status of the technical system.

From the aspect of mechanical system state, special attention should be paid to appearance and changing trends of the number of mechanical particles in the oil. The second focus would be state of the lubricant, where it is significant to consider the signs that point to appearance of viscosity, increase of oxidation and additive wasting. The third focus includes the state of impurities in oil, where attention should be paid to the quantity of particles, water content and metallic impurities. Theoretically, oil analyses are divided into three classes. In reality, all three classes of status monitoring are interconnected and must be observed as a whole.

In practice, it is common to talk about conventional or classical laboratory technique and methodology of quality control of lubricant on the one hand, and on the other hand, about modern instrumental technique which has been perfected during the past years so much that it provides desired data. Considering the complexity of this problem, in practice, of course depending on equipment of certain laboratories, all known methods of examining lubricant characteristics changes during exploitation are used. For years, most laboratories examined certain physical and chemical changes, such as:
– viscosity on various temperatures,
– ignition temperature,
– neutralizing number (acidic number),
– content of non-soluble materials in organic solvents,
– content of fuel,
– content of water,
– color.

With further perfection of methods, these examinations have expanded also to certain contaminations of lubricants with metallic particles, as well as to determining the very chemical change in oil, not only qualitatively but also quantitatively.

Table 1. Physical and chemical characteristics of oil

x	y	visc40	visc100	IV	TP	TBN	TAN
new oil	0 m/hr	103,12	13.82	135	234	8,89	2,69
2	100 m/hr	103,97	14,01	136	224	9,4	3,06
3	160 m/hr	103,84	14,17	139	218	9,4	3,17
4	200 m/hr	102,86	14,11	140	222	9,43	3,22
5	243m/hr	102,79	14,03	138	224	9,38	3,22
6	0 m/hr	110,07	14,59	136	237	10,18	2,71
7	100 m/hr	104,37	14,09	137	228	9,7	3,06
8	200 m/hr	104,17	14,06	137	230	9,7	3,19
9	246 m/hr	103,85	14,05	137	235	9,6	3,18
10	0 m/hr	112,7	15,15	140	234	10,05	2,93
11	120 m/hr	98,87	13,83	141	225	9,39	2,75
12	270 m/hr	94,74	13,51	143	227	9,46	2,87

Table 2. Presence of mechanical impurities in oil

Fe	Cu	Pb	Al	Cr	m/hr
11,65	1,92	5,96	0	0	33271
7,11	0,91	1,88	4,57	0	33371
5,66	0,61	1,89	4,58	0	33431
9,13	0,69	2,52	5,74	0	33471
5,85	0,7	1,87	11,34	0	33514
11,46	0,86	0	0	0	33750
3,89	0,8	1,24	6,79	0	33850
4,95	0,41	1,9	29,98	0	33950
5,43	0,41	2,53	16,08	0	33996
19,8	0,92	5,65	0	0	
5,57	0,43	1,22	15,9	2,46	34116
4,94	0,65	2,43	18,14	1,64	34266

Today, the most significant are the following methods:
– gas chromatography,
– atomic absorption and emission spectroscopy,
– infrared spectroscopy,
– ultraviolet spectroscopy,
– mass spectroscopy,
– nuclear magnetic resonance.

In this research the following methods were employed:

a) To determine changes in physical and chemical oil characteristics:

– Kinematic viscosity (mm²/s) on temperatures 40°/C and 100°/C – examination conducted according to standard BAS ISO 3104 and DIN 51526,

– Viscosity index – examination conducted according to standard BAS ISO 2909 and ASTM D 2207,
– Ignition point – examination conducted according to standard ISO 2592 and ASTM D 92,
– Total basis number (TBN) (mgKOH/g) – examination conducted according to standard BAS ISO 3771,
– Neutralization number (TAN) (mgKOH/g) – examination conducted according to standard ASTM 664.

b) In order to determine metal content (Fe, Cu, Al, Pb) (mg/kg-ppm) – examination conducted according to standard ASTM D 5863, that is, atomic absorption spectrometry was applied.

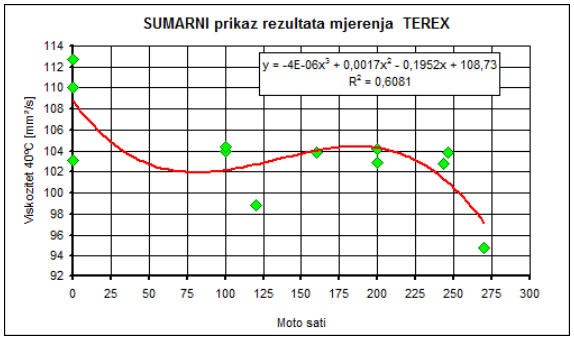
3.7. Results of experiments

In the following tables the results of researching physical and chemical characteristics of oil and presence of mechanical impurities in oil are represented. Here, only the results for diesel motor CUMMINS – KTA 50 C, which is built in a dumper Mark 36 internal mark (11) are shown. Laboratory examinations of oil were conducted in Oil refinery Modriča.

Upon laboratory examinations of oil and data analysis, a regression analysis was conducted for every characteristic separately in order to determine the trend, that is to establish mathematical models of oil characteristics changes and presence of mechanical impurities (presence of metals) in accordance to time of oil exploitation.
In this research, accent was given to determining the trend of presence of metals in oil, in order to diagnose status of tribological systems in diesel engines.

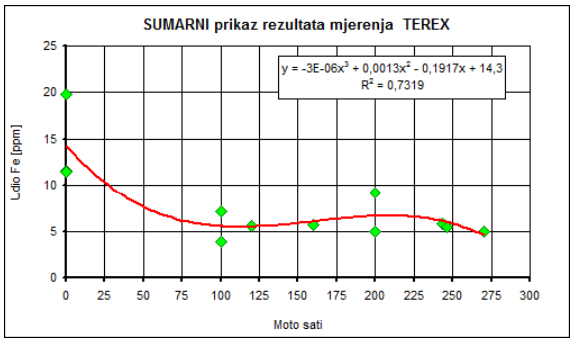
The following picture shows dependence between change in viscosity and time of oil exploitation.

SUMMARY REPRESENTATION OF TEREX MEASUREMENT

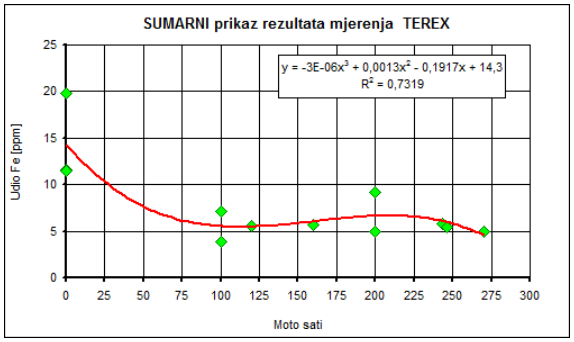


Picture 1. Viscosity at 40°
x = motor hours, y = Viscosity at 40°

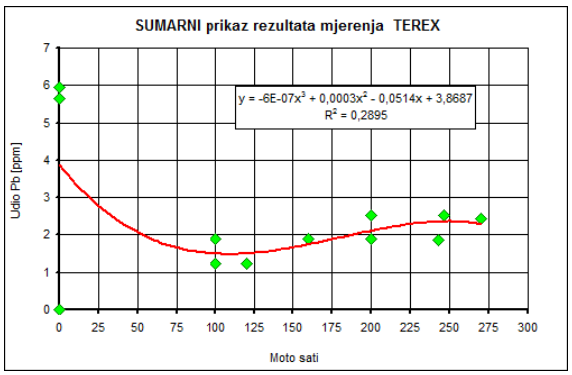
The following pictures show dependence between the change of presence of metals and oil exploitation time.



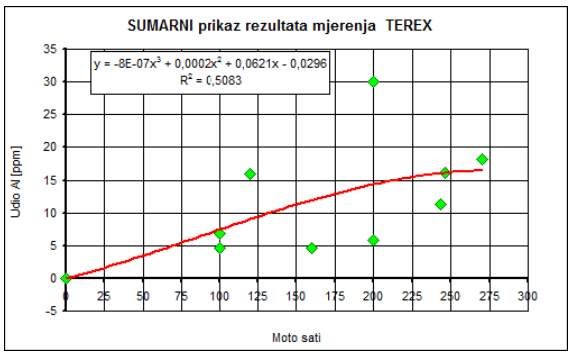
Picture 2. Presence of Fe in oil



Picture 3. Presence of Cu in oil



Picture 4. Presence of Pb in oil



Picture 5. Presence of Al in oil

4. CONCLUDING CONSIDERATIONS

In hard coal mine Banovići there are 40 CUMMINS motors in exploitation at this time, of which 17 are built in dumper trucks of bearing capacity 1000 – 1700 [KN]. For each of these motor temporal status image is being followed every day. In addition, for every type of these motors a data base has been set up, which contains basic technical data with all necessary instructions (servicing instructions, repair instructions, etc.). In accordance with manufacturer's instructions, all motors regularly undergo: daily inspection, servicing, smaller, middle-scale and large repairs. Diagnosing working parameters of motors is also conducted regularly. In this research, diagnosing status of tribological mechanisms is presented, and this was conducted employing diagnostic methods of scuffing products control (control of mechanical impurities in motor oil).
Acquired results by using the above-mentioned two diagnostic methods are satisfactory. Absence of atomic absorption spectroscopy is due to the fact that it does not provide information about size of mechanical impurities, but only about their quantity.
Further research should be directed at constructing a program for diagnosing tribological assemblies of motors with the aim of extending the interval between oil changes, longer motor work and reaching prognoses regarding motors' functionality in the future.

5. BIBLIOGRAPHY

[1] Adamović Ž., Tehnička dijagnostika, Zavod za udžbenike i nastavna sredstva, Beograd,
1996.
[2] Ekinović S., Osnovi tribologije i sistema podmazivanja, Mašinski fakultet u Zenici, Zenica, 2000.
[3] Avdić H., Tufekčić Dž., Karić A., Vibration Influence on operational status of complex technical systems, 2nd DAAAM International Conference on ATDC 03, Tuzla, 2003.
[4] Sebastijanović S., Karić A., Tufekčić Dž., Tribološki efekti kod elastohidrodinamičkog podmazivanja XXVIII Naučno – stručni skup o održavanju mašina i opreme, Budva, 17-20 juni 2003.
[5] Karić A., Istraživanje modela klizajućeg trošenja za parcijalne kontakte, PhD thesis, Mašinski fakultet, Tuzla, 2008.
[6] H. Avdić., Dž. Tufekčić., A. Karić., Infuence of qualitative characteristics of technical construction on maintainability, 6th International research/expert conference TMT 2002, Neum, 2002.