POSSIBILITIES FOR OPTIMIZING MAINTENANCE OF MILITARY VEHICLES ON THE RESULTS OF TRIBOLOGICAL DIAGNOSTICS

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Abstract: *Tribological diagnostics is a non-destructive and non-disassembling diagnostic method, that uses lubricating oil as a source of information about processes and changes in mechanical systems, to which it is applied. The paper deals with the mathematical processing, monitoring and analysis of the oil field data obtained from the atomic emission spectrometry in frame of the tribodiagnostic oil tests. The mathematical methods based on a regression analysis and calculations are used in the paper for oil data analysis. The whole assessment procedure and their outcomes serve as identification of a suitable approximation trend. With the same result we are capable of determining in-service operation history as well as giving inputs to maintenance optimisation. Nowadays the system requirements are set up and evaluated in various manners. We would like to keep both preventive and corrective maintenance costs as low as possible. A system design and a maintenance system help to fulfil this task. We propose to use one of the approximations presented in order to track the system operation behaviour.*

Keywords: TRIBODIAGNOSTIC, WEAR, OPERATION ASSESSMENT, MAINTENANCE OPTIMISATION

1. Introduction

The growing dependability and operation safety requirements for modern equipment together with the increasing complexity and continuous attempts to reduce operation and maintenance costs might be satisfied among others by the consistent use of modern diagnostic systems. The main task of object technical state diagnostics is not only to find out incurred failures, but also to prevent from the failure occurrence with the help of sensible detection and changes localization in the object structure and in its behaviour changes. A tribotechnical system (TTS), friction in it, wear and lubrication, and especially the outcomes of it are the subjects of our major concern. Regarding the tribotechnical system, the basic information about tribological process, operating and loss variables are provided. Tribology is the science and technology of interacting surfaces in relative motion. The function of a tribotechnical system is to use the system structure to convert input variables (e.g. input torque, input speed, the input type of motion, and the sequence of motions) into technically utilizable output variables (e.g., output torque, output speed, output motion) [1, 2].

The type of interaction occurring primarily depends greatly on the friction state. Thus, when a lubricant is present, the atomic/molecular interaction can be disregarded more often than the mechanical. Friction and wear in a given TTS ultimately depend on the interactions between the elements. The friction state, the effective mechanisms of friction and wear, and the contact state can be used to describe the interactions. The tribologic loads occurring in the real contact areas produce tribologic processes. They subsume the dynamic physical and chemical mechanisms of friction and wear and boundary-layer processes that can be attributed to friction and wear.

Owing to the TTS we have got a lot of diagnostic oil data. In view of tribo-diagnostics this data is considered to be the final outcome. This data can tell us a lot about lubricants / life fluids quality itself as well as about system condition. From the reliability, maintainability and safety point of view we consider such data to be very valuable. We distinguish different methods for oil / life fluids samples analysing. These methods are used to determine physical quality of the sample. Since the system operation, taking the oil samples and the outcomes themselves, are very fuzzy, we later expect to adapt some approaches from the fuzzy logic theory to help.

The procedure and results presented bellow are based on standard mathematical principles – a regression function and a regression analysis. Later these will be supported by fuzzy logic approaches.

We present results which contribute to general approach when considering both the maintenance procedures and the cost analysis optimisation. From both presumptions we are expecting some costs savings. As for the military point of view we would like to determine remaining “time units” in order to perform the mission.

Following the regression analysis performed beforehand it is possible among others to assess the operating history of an observed vehicle. When analyzing the data we focus on such chemical substances in oil which are somehow interesting for us. These are the products of mechanical processes and wear. The elements originated either in bearings or different parts of kinematic accouplements. We do not take into account any additives. The elements of our primary concern are ferrum, cuprum and lead. It results from the observations and performed analyses that ferrum behaves presumably in the most interesting manner. Therefore we are going into it in a more detailed way.

We do not mention all the results of regression analyses in the paper (especially not for lead and cuprum).

However, after comparing them, we have come to the following conclusions:

- The dependence of cuprum on operating hour (Mh) is not evident so it does not bring us to any common conclusion.
- When dealing with the dependence of lead on operating hour (Mh), there are similarities among all kinds of vehicles, but the multiple correlation coefficient of a tank and infantry fighting vehicle data is too small for a relevant regression function to describe selected data well.
- When dealing with the dependence of ferrum on operating hour, there are also similarities among all kinds of vehicles, but a multiple correlation coefficient is higher. Therefore it is convenient to concentrate only on the dependence of ferrum on Mh.

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 [1,2,3,].

2. Objects of diagnostics and diagnostics methods

The assumed objects of diagnostics, i.e. the tank engines T-72M4CZ, TATRA 810 and BMP II have not been ready yet in terms of design to use the ON-LINE system, though in practice similar possibilities for other applications have already existed. It results from the information stated above that we are still supposed to use OFF-LINE engine diagnostics system when sampling lubrication fluid at certain intervals, and using known and optimised special tribodiagnostic methods [4], [5], [6] and [7].

The recognition of a technical state is a basic assumption for making a diagnosis used for determining either operability or non-operability, or for the detection, recognition, distinction, and localization of system parts faults. Although the data on the object condition obtained from a lubrication fluid is available, little importance is attached to it when changing the oil. If the condition of lubrication fluid affected not only evaluation of the object condition, but also modification and optimisation of exchange dates, it would be notably positive in terms of economic optimisation. When evaluating data, the information is transformed many times and provides only estimated reality which might be different from reality itself. That is why the pattern recognition is an important and very complex area of technical diagnostics. Generally the recognition is divided into two groups depending on which methods are used - syntactic or signature. A Parsing/Syntactic Method – is based on recognizing a qualitative way. A word or a symbol string represents the pattern reflecting an object, an event or a process. A Signature Method – is based on recognizing objects, events, or processes with the help of an arranged set of numbers which describe the object characteristics. In diagnostics in many cases there is no exact line between an up state and fault, i.e. there is no mutually explicit representation among points spaces and points classes spaces and corresponding technical states – diagnoses. The failure classes intersect which means that the same magnitudes of measured characteristics might correspond with different diagnoses. If the vagueness in classes distribution is not given by a stochastic character of measured characteristics but by the fact that the exact line among states classes does not exists, it will be later on good to use fuzzy set theory and adequate multi-criteria fuzzy logic. One of the most important information sources might be the results of ferographical analysis (a type, a size, material composition, distribution, morphology, speed of generation, etc.) and particles wear in real time, or lubrication oil degradation got by the methods FTIR, etc. However, it has not been possible to get this information in real time yet. In our case we use the results and information from atomic emission spectrometry. Following this analysis we can obtain the information about the presence of the elements of a specific kind and the amount of elements. However, we cannot identify their origin – e.g. as a result of fatigue, cutting or sliding. Therefore in our further research we try to identify where the elements might come from.

3. Oil field data asseeement

Having enough field data obtained from a statistically important set of diagnosed objects is a basic assumption that we will solve this problem successfully (e.g. the engines themselves, etc.). Since the data sets are very extensive, we are not going to introduce them here except for a part/example of ferrum particles found in an infantry fighting vehicle engine. But we deal with dozens of samples taken and analysed at different types of observed engines. In certain aspects we consider the engine in an infantry fighting vehicle II to be a reference object, because the event of a failure type has occurred in it. All tribodiagnostic processes related to the failure occurrence have been recorded.

Technical state diagnostics and engine monitoring includes system approach which deals with sampling, analysis and information utilisation which is important in relation to a mechanical or thermodynamic engine state. Generally it is about monitoring and assessing wearing particles and pollution in life fluids (e.g. hydraulic and engine oils), or metal wearing particles monitoring, non-metal polluting particles monitoring, products of burning process by high or low temperatures, soft pollutants of organic origin which form oil resin, so called cold sediments, oil and fuels oxidation products, hard-solid pollutants of inorganic origin, dust particles of silicon origin, etc. The monitoring covers a life fluid sample collection and its off-line analysis using easy, standard or special – instrumental methods. The increased forming of metal magnetic wearing particles is usually monitored too, using magnetic detectors with recording and signalization. Using the on-line diagnostics based on a laser particles analyser appears to be a very progressive method. This method enables us to find wearing particles according to a corresponding wearing mechanism (fatigue), adhesion, abrasion, cavitations, corrosion, vibration, combination of the situations mentioned above together with expressing the state, prognosis, trends calculations, etc., supported by intelligent software in the future in real time [3].

Utilisation of regression model

Exploring and analyzing variable dependencies, the values of which are obtained when performing an experiment, is considered to be an important statistical task. In view of their random character, a random vector $X = (X_1,\dots,X_k)$ represents independent variables and a dependent variable is represented by a random variable Y.

When describing and examining the dependence of Y on X, we use a regression analysis, and this dependence is expressed by the following regression function:

$$y = \varphi(\mathbf{x},\boldsymbol{\beta}) = E(Y \mid \mathbf{X} = \mathbf{x}), \quad (1)$$

where x = $(x_1,\dots,x_k)$ vector of independent variables, y is a dependent variable, $\boldsymbol{\beta} = (\beta_1,\dots,\beta_m)$ vector of regression coefficients βj.

For our data we will look for a regression function in a linear form and we will apply a linear regression model:

$$y = \sum_{j=1}^{m} \beta_j f_j(\mathbf{x}), \quad (2)$$

where $f_j(\mathbf{x})$ are well-known functions where $\beta_1,\dots,\beta_m$ are not involved.

4. Proposals for system health and condition monitoring based on the results of tribodiagnostics

In the case of taking single oil samples a time line might be possibly not stationary, and before making next calculation it needs to become stationary (non-constant mean value and dispersion); standard transformations do not provide satisfactory results.

The analysis results detected from the oil provide a potential space for the modification of oil exchangeable date considering the number of particles present in the oil before the actual change. The situation is interesting especially with regard to the velocity of their occurrence. A recognized number of particles before the actual change would not necessarily mean a critical number which could threat reliable engine function or cause an accident. However, the exchange date is determined by an oil producer, and the time period in which the exchange is performed might be significantly affected by other characteristics. The presence and the number of particles which occurred in a lubricating system by mechanical processes should be viewed in the future as one of the most important factors in the process of lubrication fluid state assessment.

Following the results it is also necessary to decide on the approximation of real course of particles generation. On the basis of the calculations already made we estimate that the linear regression model will be the most suitable for many reasons. In Table 1there are single regression analysis models for the observed type of a vehicle.

Table 1: *Regression models comparison – outcomes.*

Regression function / Vehicle type	$y=\beta_1$	$y=\beta_1+\beta_2x$	$y=\beta_1+\beta_2x+\beta_3x^2$
Tank	y=17.945 $r^2=0$	y=13.712+0.0949x H: $\beta_2=0$ is rejected for $\alpha=0.05$ $r^2=0.3856$	$y=13.816+0.0882x+0.00055x^2$ H: $\beta_3=0$ is not rejected for $\alpha=0.05$ $r^2=0.3859$
APC	y=24.069 $r^2=0$	y=14.099+0.0723x H: $\beta_2=0$ is rejected for $\alpha=0.05$ $r^2=0.5022$	$y=10.373+0.1333x+0.0002x^2$ H: $\beta_3=0$ is not rejected for $\alpha=0.0005$ $r^2=0.5474$
T-810	y=15.604 $r^2=0$	y=13.561+0.0282x H: $\beta_2=0$ is rejected for $\alpha=0.05$ $r^2=0.3488$	$y=12.9132+0.0525x+0.000079x^2$ H: $\beta_3=0$ is not rejected for $\alpha=0.001$ $r^2=0.378$

It results from the Table that in all the cases it is convenient to consider the regression function in the form $y=\beta_1+\beta_2x$. The regression function $y=\beta_1$ is too simple, and does not reflect the dependence. The regression function $y=\beta_1+\beta_2x+\beta_3x^2$ reflects the dependence better than $y=\beta_1+\beta_2x$, but the coefficients β_3 are statistically unimportant and the growth of a multiple correlation coefficient is not that fast as compared with the regression function value: $y=\beta_1+\beta_2x$.

On the basis of the performed analysis we can say that we are able to assess/observe operating history. Owing to this fact it is possible to plan and verify maintenance actions or other operation of vehicles. When following the analysis results we can also come to a conclusion regarding a type of operation under which a vehicle was run. The dependencies found are shown in Fig. 1.

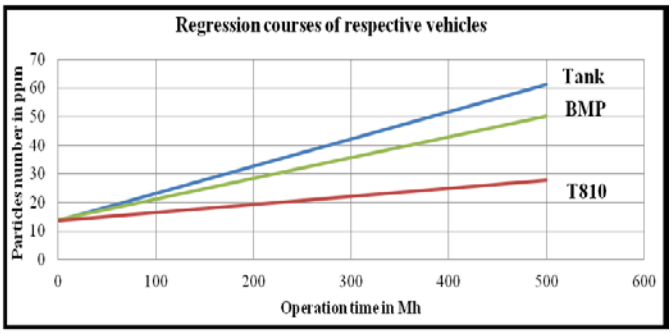

Fig. 1 *Regression courses of respective vehicle .*

Taking into account the presented results we can state that there is an objective connection between the amount of generated Fe particles and the number of operating hours. In the paper we do not address other interesting elements like cuprum or lead. The reason why we did not do it is that during performed analyses we could not verify the mathematical dependence of particles generation per operating hour.

5. Conclusions

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 [3]. Since there is a wide spectrum of suitable methods while analysing 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.

Having this tool we are capable of understanding the mechanisms of failures better. Such procedures enable us to be prepared for coming failures and progression to faults. The diagnostics is cheaper than on-line assets and failure mechanisms are determinable in advance. Some specific classifications of failures are also used in relation to risk sources and they are recognised due to oil and other life fluids diagnostics [7].

The results shown in Figure 1 for example demonstrate quite clearly that it is possible to assess the state of a system depending on oil data. It is obvious that a type of a motor data corresponds to the obtained results of the analysis and an assumed operating profile.

We believe that later in our research we will determine recommended optimum period for changing the oil. By the help of fuzzy logic [8] we expect to specify our information about operating history or the estimation of remaining operating units.

6. Literature

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