ANALYSE OF LUBRICANT LIQUIDS IN AIRCRAFT ENGINES BY TRIBOTECHNICAL DIAGNOSTICS

Janka Mihalčová, Jozef Dobránsky, Technical University of Košice, Faculty of Manufacturing Technologies with a seat in Prešov, Štúrova 31, 08001 Prešov, Slovakia

Abstract: Tribotechnical diagnosis is a method on non-destructive diagnostics which evaluates conditions of a tribotechnically observed equipment and provides in very short time a diagnostic information. For early detection of failures of aircraft engines, mechanisms of their abnormal consumption and wearing off and degradation of lubricants, the laboratory utilises the following techniques: spectrometric methods, particle size and distribution analysis, ferrography, measurements of physical and chemical properties of oils. Atomic emission spectrometry and infrared spectrometry are used from spectrometric methods. Apparatus for particle size analysis includes an atomic particle counter and the ferrographic analysis informs also about the morphology of the worn out particles. Physico-chemical properties of oils are determined using an automatic titrator for measurements of water content and acidity. Their viscosity is measured by a viscosimeter. These analytic methods are used for oil quality evaluations any closed lubrication system, in engines, gearboxes, compressors and pumps.

Key words: tribotechnical diagnostics, infrared spectrometry, oil, engines

1. INTRODUCTION

The decisive reason for introduction of tribotechnical diagnostics to their civic or military aircraft was of a necessity to increase safety and reliability of aviation and extention of technical lifetime of engines. In our tribotechnical laboratory constituted of an atomised computer controlled diagnostic station the following equipment is used for analyses of samples of used aircraft engine oils and hydraulic liquids: a SPECTROIL M atomic emission spectrometer with rotating disc electrode, a SPECTRUM 1000 infrared spectrometer with Fourier transformation, a MET ONE particle counter with a laser probe, a ferographic set consisting of a Ferrograph REO 1, Ferrometer REO 21 and a ZEISS dichromatic microscope, a TITRINO 702 SM automatic titrator and a TAMSON TV 2000/AKV viscosimeter.[1] The goal of using these methods is to provide accurate information for:

- detection of abnormal wornness which immediately precedes failure,
- diagnostics of type, location and mechanism of wornness, as well as its progress,
- forecast of conditions of a machine or a tribotechnical point,
- decisions on necessity of maintenance or repair.

The essence of a tribotechnical analysis is to evaluate presence of worn off particles in an oil system, to determine their concentration, number, geometric parameters and physical and chemical properties of the lubricant.

a) tribotechnical diagnostics fulfils the following tasks: to observe conditions and wornness of machines and equipment of the basis of determination of worn off metal particles in lubricants, where the tendency of measured values is important,
b) to determine lubricants useful lifetime by determination of the degree of their
devaluation by products of thermal and oxidation processes as well as by external
contaminants. Increased amount of contaminants in oil means not only higher wearing
off for lubricated parts, but also formation of sediments which may clog oil holes and
grooves of machines,

c) to determine optimum regular intervals for oil exchange.
There are diagnostical signals which, at convenient selection of an index for checktime
interval, allow to characterise continuously technical conditions of the observed point. A
characteristic dependence of deterioration index on time can be obtained by regular checks
and measurements during increasing working time of a machine or a certain point. [2,3]

![General curve for deterioration index as dependence of operation time](image)

**Fig.1 General curve for deterioration index as dependence of operation time**

Knowledge of such characteristics shown on fig. 1 allows to evaluate operating conditions by
simple reading from measuring equipment and by a comparison using a convenient criterion.
The process of wearing out is individual and characteristic for each tribotechnical system and
it can be described by a theoretical curve. [4] The curve of a wear out rate shown on fig. 2
shows consequent phases characterised by change of wear out rate and wornness itself:
1. Start-up phase [I] – the wear out rate is high and slowly decreases
2. Lifetime phase [II] – the wear out rate is low and constant
3. Lifetime limit phase [III] – is characterised by steep increase of wornness

![Wornness rate curve](image)

**Fig.2 Wornness rate curve**
2. EXPERIMENTAL

SPECTROIL M atomic absorption spectrometer with rotating disc electrode from SPECTRO CS company is used for determination of metal concentration in oils. The equipment provides quantity of elements present in natural or synthetic oil derivates. It provides analysis for 21 metals, namely worn off particles: Fe, Al, Cr, Cu, Sn, Pb, Ag, Ti, Ni, W, V, oil additives: Ca, Mg, Ba, Zn, P, Mo and contaminants: Si, Na, K. The instrument is calibrated before each analysis using CONOSTAN (METALLO-ORGANIC STANDARDS) oil standards and the results are in ppm units, eg. in μg/ml. [5] PERKIN-ELMER infrared spectrometer with Fourier transformation provides observation of changes in physical and chemical quality of used oils comparing to new ones of the same type. The FT-IR spectrometer uses Michelsons interferometer which amplifies or attenuates radiation from a polychromatic source accordingly using interference. The signal is modified in the computer unit using Fourier transformation to provide an infrared absorption spectrum. MET ONE automatic particle counter from SPECTRO CS works on principles of particle screening using laser probe in a window of 800 μm x 800 μm and counts the particles in oil according to their size. The result is obtained in form of number of particles whose dimension exceeds certain values (for example more then 5, 10, 15, 20, 25, … 100 μg/ml of sample). The results can be evaluated using either NAS 1680 or ISO 4406 standards. The ferrographic set is used to observe number of particles and their size in oil with respect to particle morphology. The ferrographic set consists of a REO 1 FERROGRAPH, a REO 21 FERROMETER and a ZEISS dichromatic microscope. Ferrography is a novel technique used for analysis of worn off debris. It is a method based on separation of friction pairs being separated during wearing out of those pairs from the oil itself. TITRINO 702 SM automatic titrator from DONAU LAB is used for determination of water content according Karl Fischer and acidity. A complete tribotechnical diagnostics includes also determination of kinematic viscosity of oils measured by TAMSON TV 2000/AKV viscosimeter at 40 °C and 100 °C using a capillary tube immersed to a thermostat controlled bath.

3. RESULTS AND DISCUSSION

The first analysis performed in tribotechnical diagnostics is in AES with rotating disc electrode where the basic information on presence of undesirable worn off elements in oil is obtained, however only for particles of less then 10 μm. The AES results are shown in table 1 as a dependence on flight time (number of hours flown by an airplane with the same oil without exchange). The second analysis is performed on a particle counter where information on numbers of all particles are obtained according to their size distribution. This analysis decides on necessity of further ferrographic analysis. As the values obtained by the counter where high ferrographic analysis was performed as well. The reason for high numbers after particle counting was that the counter counted in also newly formed clots which were formed in one case during preparation of ferrograms. The microscope revealed small coagulations with size of several tens of micrometers. Repeated preparation of ferrograms showed that these coagulations come from the analysed oil and not for technical petrol used for experiments. It was found that they are friction polymers which are formed during overload of lubricants in critical points. Their structure is a result of polymerization of oil molecules to large aggregate structures. Friction polymers are usually formed after oils are heated to high temperatures. 

As several other samples from the same engine showed coagulation during ferrographic analysis the samples from this engine where treated with increased attention.
According to analyses of samples which formed coagulations it was first of all necessary to judge whether such working liquid is capable of further use. It was also necessary to find out whether the colloidal clots formed after mixing with technical petrol were originated during use due to contacts with oil washed construction parts of engines and how such quality of working liquid may affect technical conditions of the engine.

The following table contains oil samples from the observed engine ranked according to flying time (number of hours flown by an airplane with the same oil without exchange). Beginning with sample 213 the flight time is low, it means that the oil in the engine has been exchange after recommendation of tribotechnical laboratory. This conclusion was achieved after a complete tribotechnical analysis.

From table 1 we can see that polymers do not cause any excessive wornness of construction parts of the engine, as no limit values of worn off metal contents have been reached. It is generally known that polymers enhance lubrication.

**table 1. Element contents from an engine measured with SPECTROIL M using AES method with rotating disc electrode as dependence of flight time (flight time - number of hours flown by an airplane with the same oil without change)**

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Flight time (hours)</th>
<th>Observed elements (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fe</td>
</tr>
<tr>
<td>2000028</td>
<td>54</td>
<td>3,4</td>
</tr>
<tr>
<td>2000034</td>
<td>61</td>
<td>3,5</td>
</tr>
<tr>
<td>2000095</td>
<td>68</td>
<td>2,5</td>
</tr>
<tr>
<td>2000116</td>
<td>75</td>
<td>2,1</td>
</tr>
<tr>
<td>2000118</td>
<td>78</td>
<td>3,2</td>
</tr>
<tr>
<td>2000213</td>
<td>2</td>
<td>4,8</td>
</tr>
<tr>
<td>2000262</td>
<td>11</td>
<td>2,0</td>
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<tr>
<td>2000191</td>
<td>18</td>
<td>1,3</td>
</tr>
<tr>
<td>2000347</td>
<td>25</td>
<td>1,7</td>
</tr>
</tbody>
</table>

Comparing infrared spectra of the above oil samples shown on figure 3 for the entire spectral range to that of an ASTO-555 pure synthetic oil for jet engines, no remarkable differences have been found. This shows very small chemical variations of samples which are originated in the oil system of the engine.

Figure 3 shows infrared spectra of selected samples describing the general course of changes. Description of figure 3:

A - infrared spectrum for ASTO-555 pure synthetic oil
B - the first sample from particular engine after 54 hours flown
C - the last sample from the engine – prior to recommended oil exchange after 77,5 hours flown
D - the first sample after oil exchange after 1,5 hours flown
E – the last delivered sample after 24,5 hours flown

Comparison of a differential spectrum with a spectrum of pure oil using FT-IR found an insignificant content of compounds being formed during thermal oxidation of oil. The range and rate of oxidation changes depend on chemical composition of oils and mainly on temperature. Thus it is more accurate to talk about thermo-oxidation reactions or thermo-oxidation stability of oils. These products of thermo-oxidation in oils appear especially after the oil content has been heated above its working temperature. It is assumed that peroxiradicals are the first oxidation product which are then converted to more stable compounds as acids, lactones and finally oil carbenes and carboids.
Fig. 3 Comparison of used oil sample records with pure ASTO-555 oil using SPECTRUM 1000 FT-IR equipment

Only a complex tribotechnical analysis can provide correct results. It is known that it is very hard to remove newly formed friction polymers from the oil. After flushing of the engine they appear again in ferrographic results. It is reasonable to be afraid of the situation where the above polymers would clog oil filters and open a safety bypass enabling contaminants and worn off products to proceed to working space of engines. This could not only affect the quality of oil but could seriously endanger flight safety.

4. CONCLUSIONS

It is estimated that 80-90 % of engines are ceased because of wormness where often only thin surface layers are worn out. 85 % of failures of roll bearings is caused by failure of tribotechnics.

The more long-term an engine is monitored the more accurate and better is the diagnostics of its wormness. The above example is not a typical everyday example of tribotechnical analysis. The main role of the Tribotechnical laboratory is to monitor conditions of military aircraft and ensuring its safe and failure-free operation.

The goals of development and utilisation of the above techniques is to reveal any potential failure during its pre-development phase before it causes serious collapse. In diagnostics it is very important to pay attention also to further information. It is necessary to prepare resolution of final state of the engines, knowing processes taking place in the engine at normal functioning as well as during development of any failure.

5. REFERENCES


ADDRESS FOR CORRESPONDANCE

SLOVAKIA
Ing. Jozef DOBRÁNSKY, PhD.
Technical university of Košice
Faculty of manufacturing technologies with a seat in Prešov
Department of technology systems operation
080 01 Prešov
SLOVAKIA
e-mail: dobransky.jozef@gmail.com