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EXAMPLE OF AN INTEGRATED CONCEPTION USE OF METHODS FOR MONITORING WEAR PARTICLES IN THE LUBRICATION SYSTEM OF AIRCRAFT

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Tribotechnical diagnostics as an integrated conception deals with the assessment of lubricants properties, monitoring of behaviour and consequences of the lubricant degradation process during its work in the machine lubrication system. For tribodiagnostic of friction pairs of aircraft engine are used three basic methods dealing with the qualitative and quantitative determination of wear particles, which are in oil of the lubrication system. Concentration of elements was determined by optical emission spectrometry with rotating disc electrode (RD OES) application, categorization of particles by dimension and quantity was performed by method of optical shading. By usage of ferrographic analysis was studied morphology of wear particles. On particular example of monitoring of aircraft engine is typified mode of notice its condition with aim increasing the safety of operation and reduction ecological load by prolongation duration of renewal lubrication system given by manufacturer of device.
Key words: tribodiagnostic methods, optical emission spectrometry with rotating disc electrode, cleanness of oil, ferrography.

Primjer integrirane koncepcije korištenjem metode praćenja trošenja čestica u sustavu podmazivanja zrakoplova. Tribološka tehnička dijagnostika kao integrirani koncept bavi se procjenom svojstava maziva, praćenjem ponašanja i posljedicama razgradnje maziva za vrijeme svog rada u sustavu za podmazivanje stroja. Za tribološku dijagnostiku tarnih parova motora zrakoplova koriste se tri osnovne metode koje se bave s kvalitativnim i kvantitativnim određivanjem trošenja čestica, koje su u ulju sustava za podmazivanje. Koncentracija elemenata je određena optičkom emisijskom spektrometrijom primjenom rotirajućih disk elektroda (optical emission spectrometry with rotating disc electrode - RD OES), kategorizacija veličine čestice i količine provedene su pomoću metode optičkog sjenčanja. Primjenom ferografske analize proučava se morfologija trošenja čestice. Na konkretnom primjeru praćenja motora zrakoplova tipiziran je način uočavanja stanja s ciljem povećanja sigurnosti rada i smanjenja ekološkog opterećenja produljenjem trajanja obnavljanja sustava za podmazivanje kojeg je specificirao proizvođač uređaja.
Ključne riječi: metode tribološke dijagnostike, optički emisijski spektrometar s rotirajućim disk elektrodama, čistoća ulja, ferografija.

INTRODUCTION

According to accruing financial needs for service of machines, buying of oils and especially for assigned of safety and increasing reliability of the operation, and in not least line is aim to prolong life-time of oil in lubrication system, with that reduction ecological load with oil material, raises the demand to implement system of preventive maintenance. Tribotechnical diagnosis is applied for any closed lubrication systems, which are situated for example in gas turbine, diesel and fuel engine, gearboxes, compressors and hydraulics systems [1, 2].

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 [3]. Tribotechnical diagnostics fulfils the following tasks:

a) 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 [4].

By activity of friction pairs in lubrication system are vacates of metals and their alloy by wearing off. Wear particles are taken along by lubrication oil from friction place and together with oil circulate in lubrication system. With arising of wearing off increase the amount and size of those particles. These particles affect as catalysts of oxidation processes in oil and they are the base of oil degradation [5]. Lubrication oils are during their operation in lubrication system of engine exposed to the high temperatures, pressures and leaking undesirable materials from outside. These factors cause troubles with functionally quality of oils and materials of mechanical components of lubrication system. The origin of degradation products and the contamination of oil from outside cause decrease of additives. The durability of oil to these processes defines its degree of life-cycle [1, 6].

At present in the tribotechnical laboratories are built-up modern oil analysis program, by the means whose oil samples analysis finds out and interprets quality of oil. And this allows promptly call attention to rising failure, eventually to locate mechanical defect. To be effective tribotechnical diagnostics, the tribotechnical laboratory utilizes methods for quantitatively and qualitatively determination of wear particles for machine condition and methods for estimate of physic-chemical characteristics of oil for oil condition [7]. The configuration and required instrumentation for appraising particles in oil samples is shown in Fig. 1 bellow. In this system, measurements from each instrument are sent to the central file computer where the results are incorporated into history file for each specific machine.

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.

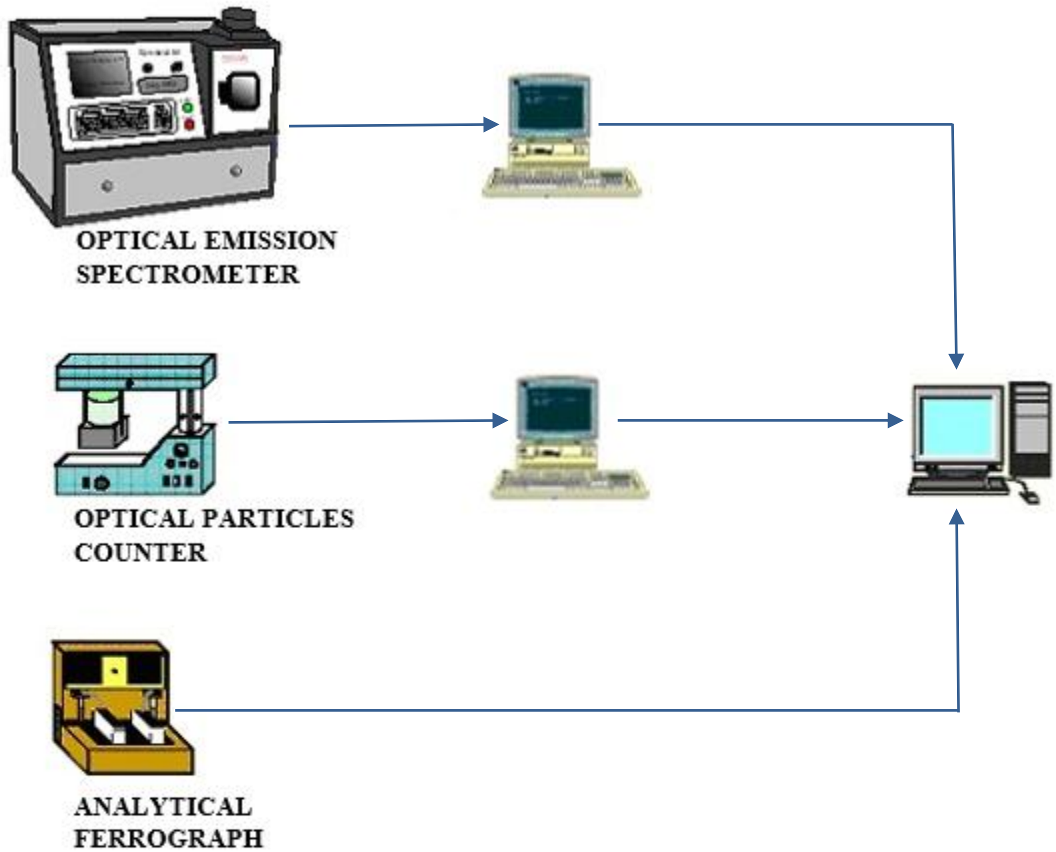

Figure 1. The configuration of oil analysis program of tribotechnical laboratory for appraising particles in lubrication filling of aircraft
Slika 1. Konfiguracija programa za analizu ulja tribološko tehničkog laboratorija za ocjenjivanje čestice u punjenju podmazivanja zrakoplova

The main goal of this study was to check the activity of the TiO_2 films within different concentrations of dyes and with the use of different UV lamps (with predominant radiation wavelengths of 365 and 254 nm).

MATERIAL AND METHODS

Optical emission spectrometry

For analysis was used optical emission spectrometer SPECTROIL M from SPECTRO APS company, Slovakia with application of rotating disc electrode. It can provides the determination of the concentration of 21 chemical elements, which to develop from wearing of engine, leaking from outside or come from additives. Determination of these chemical elements lasts 30 second. For measurement is used graphite electrode. Used oil sample is located in pattern from which rotating disc electrode by constant rate bring up oil into interelectrode space [8].

Precision and accuracy of RD OES method was determined for concentration of Fe, Al, Cr, Cu, Mg, Ni, Si, Ti, B, Pb, Sn, Ag, Na a Mo according by ASTM D 6595-00 in range from 1 to 5 μg/g with extend uncertainty U=52%, in range from 5 to 10 μg/g with U=32% and in range from 10 to 100 μg/g with U=22%, with cover coefficient $k = 2$. Traceability of the method was assigned by organo-metallic multi-elemental standard reference material NIST SRM 1084a.

Concentration and quality of elements, which are in oil during their operation in lubrication system, are very important information for locating of wear of friction pairs. Method serves for identification of decrease of additives and leaking of contaminates, too.

The monitored elements are separate by their origin in the following group [7, 9]:

- wear elements: Fe, Cr, Al, Cu, Pb, Sn, Ni, Mn, Ti, Ag and Mo;
- additive elements: Zn, P, Ca, Ba, Mg, Na and B;
- contaminants: Si, Na, B and V.

Categorizing of mechanical particles

The calculation of wear mechanical particles in oil and their categorization into dimension classes is effective diagnostic method, too. For categorizing of mechanical particles in oil is used optical particles counter MET ONE from SPECTRO APS company, Slovakia. The instrument works on principles of particle screening using laser probe. Result of measurement of oil cleanness is number of particles according to specific size class in 1 ml of samples according to STN 65 6081. ISO 4406 is used for definition of oil cleanness by three cleanliness code that represents the number of particles larger than 2 μm, 5 μm and 15 μm.

Precision and accuracy of optical counting of particles method was verification for the number of particles in range from 100 to 1000 piece/ml with extend uncertainty U=27% and in range from 1000 to 20 000 piece/ml with U=21%, for cover coefficient k = 2. Traceability of this method was assigned by suspension of dust in hydraulic oil NIST SRM 2806. By detection number of particles in lubrication system and application required measures is possible to assign the safety and long life of friction components.

Ferrography

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Ferrography

Ferrography is technique applied for analysis of wear debris in lubrication oil. This method is based on separation of oil solid particles by powerful magnetic field with gradient and describes catches of wear particles. Ferrograph REO 1 from REOTRADE company, Czech was used for creation the ferrogram where trapped particles. These are observed by bichromatic microscop ZEISS Axiolab using video camera with connection to personal computer equipped with software for processing of the scanned pictures. For definition mode of wear are adjudicated the follow characteristics of isolated particles [10, 11]:

- position of particle in the created ferrogram
- orientation basic dimension of particle
- particle form
- surface morphology (colour, milling, pitting, etc.)

Identification of particles in the ferrogram and their allocation to the particular type of engine wear were ensured by the ATLAS program, Vega module for picture processing after it is transmitted by the camera to the computer screen.

There are three stage of wear of friction pairs of aircraft engines for ferrographic assessment:

- normal: sprinkle of little adhesive particles with dimension (5 – 10) μm which can cause created of chains;
- marginal: more and larger particles with dimension by 30 μm, spherical particles with diameter dimension (5-15) μm;
- critical: numbers abnormal particles with dimension (30-150) μm, e.g. particles of sliding friction with marked milling or abrasive particles shaped thin wire or helices sized above 100 μm.

Result of ferrographic analysis is purpose the kind and intensity of wear by identification of isolated particles [12]. It is a subjective method, which requires trained and experienced service staff.

RESULTS AND DISCUSSION

Example of aircraft tribodiagnostics

The integrated conception of using, as before mentioned, three tribodiagnostical methods for monitoring of wear off particles placed in lubrication system of aircrafts, is determinated by principle of methods that have certain limitation. It is estimated that 80-90 % of engines are ceased because of wornness where often only thin surface layers are worn out. 85 % of failures of roll bearings is caused by failure of tribotechnics. [1, 4, 9]

The first method RD OES inform us about chemical composition of particles, but only to size 10 μm. The second method of optical counting particles and sorting them according the size, inform us about all particles without difference of their composition and origin. The last method, that utilizing at first magnetic separation and after that microscopic observing of wear off debris is giving the information about shape and coloration particular particles, that aren´t metal and magnetic only.

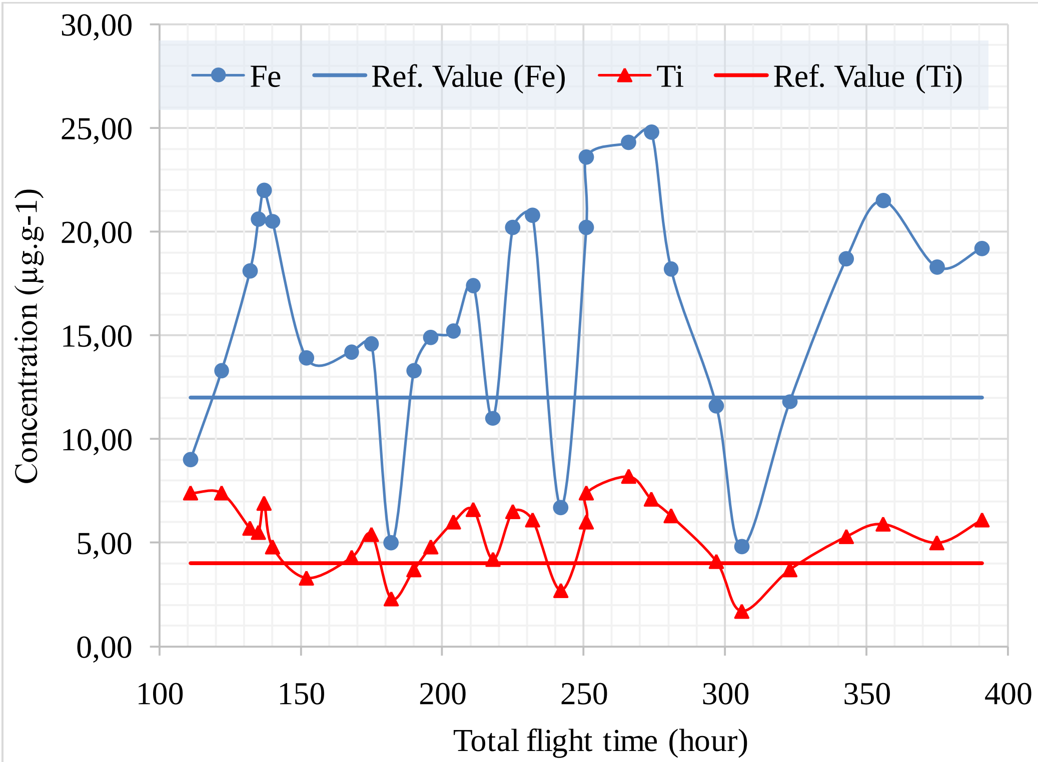

Figure 2. The course of changes in the concentration of Fe and Ti in over-all flight time
Slika 2. Tijek promjena u koncentraciji Fe i Ti za vrijeme trajanja leta

In particular example is noticed results and applications of these methods in praxis. From beginning of using methods for monitoring operations of aircraft turbosupercharged engine was noticed increased concentration Fe and Ti elements, i.e. in process of whole flight time from 111 hrs. until 391 hrs. see Fig. 2. Whole flight time present number of all flew hours, that the aircraft flown with given engine. Concentration of other diagnostically important chemical elements, they are coper, tin and aluminium, did not exceed reference value, counted for given engine model, see Tab. 1. Fe and Ti are chemical elements that are most occurring product part in materials, which are component of tribological systems, as are sliding pairs of moving parts of engine or roller bearing. In these friction nodes most marked occur wear-out of surfaces and accordly was increase of Fe and Ti concentration first monitored. In table 2 are adduced potential sources of other mentioned diagnostically important chemical elements.

Table 1. Reference concentration values of chemical element and cleanliness code defines the danger zone for the type of engine
Tablica 1. Vrijednosti referentne koncentracije kemijskih elemenata i čistoća koda definira opasne zone za tip motora

Concentration of chemical elements (*μg.g-¹*)		*U* (*μg.g-¹*)	Particles size (*μm*)	Cleanliness code
Fe	12	± 2,6	> 2	21
Ti	4	± 2,1	> 5	19
Cu	9	± 2,9	> 15	15
Sn	10	± 3,2		
Al	4	± 2,1		

Table 2. Potential sources of diagnostically important chemical elements in the aircraft engine lubrication system
Tablica 2. Potencijalni izvori dijagnostički važnih kemijskih elemenata u sustavu za podmazivanje motora zrakoplova

Chemical elements		Potential source
Fe	Iron	sliding contacts, ball and roller bearings
Ti	Titanium	sliding contacts, alloy casing
Cu	Coper	roller bearing cages
Sn	Tin	bearing cages
Al	Aluminium	light alloy casing

Table 3. The range number of particles per one millilitre oil for cleanliness code from 12 to 22 by ISO 4406
Tablica 3. Raspon brojeva čestica po jednom mililitru ulja za čistoću koda od 12 do 22 prema ISO 4406

Cleanliness code	Number of particles	
	More than	Up to and including
22	20 000	40 000
21	10 000	20 000
20	5 000	10 000
19	2 500	5 000
18	1 300	2 500
17	640	1 300
16	320	640
15	160	320
14	80	160
13	40	80
12	20	40

The ISO Cleanliness Code, ISO 4406 is the perhaps the most widely used International standard for representing the contamination level of industrial fluid power systems. Under ISO 4406 cleanliness is classified by a two number code based on the number of particles greater than 5 µm and 15 µm, see Tab. 3. However some manufacturers have expanded the code to three numbers by the addition of a code number representing the number of particles greater than 2 µm, as is in our case.

In consideration of the appearance probability of abnormal abrasion wearing and therefore also the accident probability, as safe cleanliness categories according ISO 4406 for particles bigger as 5 µm and 15 µm are declared codes 15/12. The long-term measurements of cleanness oil samples during three years of operation for these engine types was determinated safe cleanliness codes, namely 20/17/13 for particles bigger as 2 µm, 5 µm and 15 µm.

If the cleanliness categories are bigger as 21/19/14, is expected increased wearing of friction couples and define dangerous zone of operation, see Tab. 1. During operation monitored engine was recorded on optical counting apparatus mildly contamination lubrication oil of mechanical uncleanness, as you can see on the Fig. 3. The values of all cleanliness codes were almost during complete engine operation on the level of beginning critical values. In second half of engine operation, cca. after 250 working hours, was mildly increased amount particles bigger as 5 µm and 15 µm. It is noticeable, that increase amount of particles in all size categories visibly increase by increased flight time.

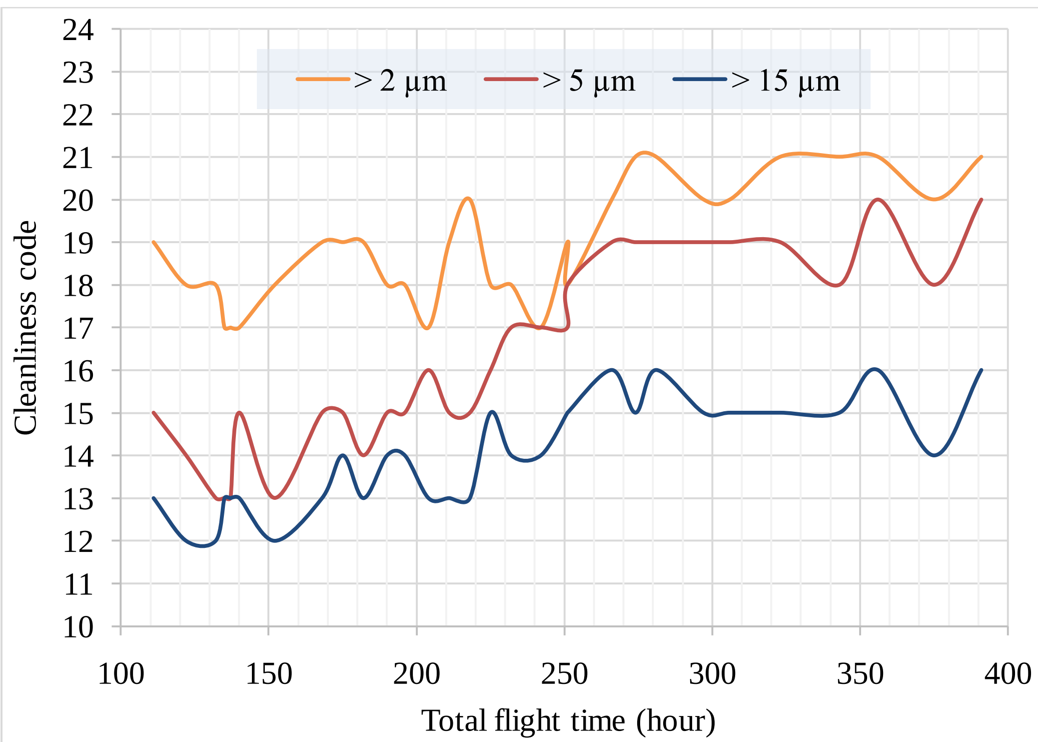

Figure 3. The course of changes in the cleanliness code of particles larger than 2 µm, 5 µm and 15 µm, depending on the total flight time over approx. 300 hours
Slika 3. Tijek promjena čistoće koda pri 2 µm, 5 µm i 15 µm, u ovisnosti o vremenu trajanja leta preko 300 sati

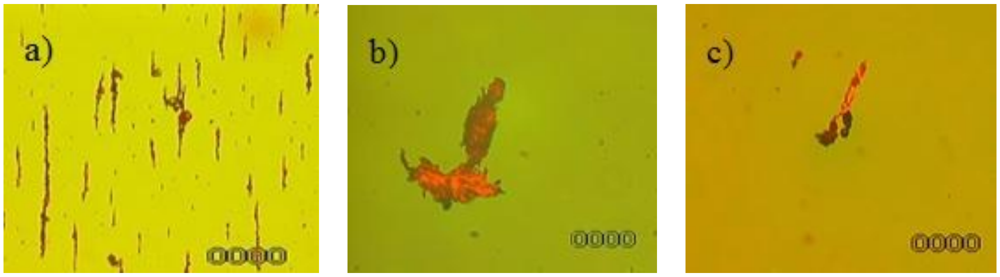

Figure 4. The demonstration of particles trapped onto the ferrograms of oil samples
Slika 4. Prikaz čestica u uzorku ulja uhvaćenih ferogramom

The results of ferrographical analyses of sampled oil samples during operational engine didn´t signalize in any case adverse mode of abrasion kinematical couples washed with lubrication oil. Analyse identify commonly so called chains of little adhesive particles, see Fig. 4a) ferromagnetic and paramagnetic particles up to 30µm, see Fig. 4 b) and small amount of spherical particles up to 5 µm, see Fig. 4c) and polymers with trapped small particles, as be seeing on the Fig. 4. The increased existence of particles from 5µm to 10µm was noticed on ferrograms. On ferrograms identified particles characterize normal wearing of friction couples and are common for engines of given model. Operation of the engine may be from tribotechnical sight consider as troublefree, but with increased concentration Fe and Ti and mildly increased amount of particles bigger than 15 µm as are common calculated values for this model of engine. Based on of these results is necessary after planed renewal of oil filling dedicates increased attention to this engine.

CONCLUSION

The decisive reason for introduction of tribotechnical diagnostics to their civic or military aircraft was a necessity to increase safety and reliability of aviation and extension of technical lifetime of engines. The more long-term of an engine is monitored the more accurate and better is the diagnostics of its wornness. The main role of the tribotechnical laboratory is to monitor conditions of military aircraft and ensuring its safe and failure-free operation. On the contribution are compiled measurement results of three methods, that define limited worn out particles characteristics, which are in lubrication systems of aircraft turbosupercharged engines. On particular example of measurement results of one engine were demonstrated as these values fluctuate during operation, as reciprocally affect but also reciprocally supplement and as together conduce to identify actual condition of engine. They on this way assist in life improving on our planet. 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.

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