MODERN AVIATION TECHNOLOGIES

UDC 621.7.036-226

Vladislav Panin, Prof.
Andriy Voznyuk
Sun Gaoyong (China)
Olaly Michel (Nigeria)

GAS TURBINE ENGINE DIAGNOSING COMPLEX METHOD DEVELOPMENT ON THE BASES OF MULTIPLE FACTORS ANALYSES

NAU Aero-engines Department
E-mail: avsacosm@nau/edu/ua

This paper dials with the method of gas turbine engine diagnosing that takes into account an engine vibrating condition, concentration of deterioration products in oil, critical elements damages accumulation and change of the compressor gas dynamical stability while in service.

Показано методичну базу для створення комплексного методу діагностування газотурбінних двигунів, який ураховує багато чинників, що виявляються під час експлуатації. Наведено приклади аналізу мастила і функціональної залежності параметрів елементів газотурбінних двигунів від процесів, які відбуваються під час напрацювання.

Introduction

With out a doubt, at any strategy of aircraft operation (by operating hours, by technical condition with parameters supervision, by reliability level supervision and until refusal), the role of diagnosing grows. This phenomenon is due to many reasons. First, aircraft operation by a technical condition, certainly, demands presence of diagnosing and forecasting methods. Secondly, engines design becomes more complicated, also flight safety requirements and flights intensity increases. Thirdly, longer gas turbine engine (GTE) service life causes increase in quantity of registered parameters.

Aircraft technical condition determination is one of main challenges during its service life.

The significant time, while aircraft is out of operation, is spent for technical condition check and malfunctions search [1].

Above specified circumstances testify undoubted importance of aircraft diagnosing methods improvement and, especially, those for aviation GTE as most complex and energetically loaded elements.

Analysis of research works and publications

Gas turbine engine diagnosing methods that allow analyzing separately an engine vibration, a flowing part condition, concentration of wears process products in oil, critical elements damages accumulation, a gasodynamical stability of compressors cascades of are used till our days [1; 2; 3; 4]. So, here are some examples. For an estimation of a vibrating condition as a diagnostic attribute vibro-speed increase or vibro-overload factor is used [3].

Also, for an estimation of a critical elements condition, turbine first stage working blade damageability value is used [2].

Fan blades, compressor and turbine disks, and also shaft can be considered as controllable units [5].

For an estimation of an engine support and gearbox condition, relative factor of iron in oil concentration growth is used [1], amount of iron in oil can be determined by the following formula

$$\Delta\overline{K}_{F_e} = \frac{K_{F_eCON}}{K_{F_eO}} - 1,$$

where K_{F_eO}, K_{F_eCON} are initial and current value of iron in oil concentration, respectively.

Similarly, it is possible to define parameter of an engine general vibration:

$$\Delta\overline{K}_V = \frac{K_{V\,CON}}{K_{VO}} - 1,$$

where K_{VO}, K_{VCON} are initial and current values of vibro-overload factors.

It is offered, that the damageability value of critical element at service [6] to be defined with use of the following formula

$$K_\tau = \frac{t_e}{\tau_e},$$

where t_e is the equivalent engine operating time accumulated by flight after flight;

τ_e is durability of a critical element at an equivalent load mode parameters.

As an equivalent load mode the full throttle mode in standard atmospheric conditions can be chosen.

It was offered, in works of A.K. Janko, to establish connection between general vibration parameter, iron in oil concentration increment relative factor value and K_τ with use of the following equation

$$K_\tau = \delta + \beta_1 \Delta \overline{K}_V + \beta_2 \Delta \overline{K}_{F_e}, \qquad (1)$$

where δ, β_1, β_2 are interrelation factors.

For identification and examination of contamination and wear metal particles, in addition to the standardized tests, there are several other oil analysis tests that have found widespread application in the last ten years can be used.

They have been oriented toward counting identifying the thousands of small particles of dirt and wear metals that are found in nearly all oil systems.

By determining particle levels and their relative sizes it is possible to detect equipment problems before there is extensive damage.

An analysis of the types of material present can indicate the source of the contamination or wear metals, and allow early corrective action.

These are five tests that have been used most frequently. For example: wear metals analysis (atomic absorption).

In this procedure the oil sample is burned in a high temperature flame, and this equipment detects how much energy was absorbed by a particular chemical element such as iron or tin. The equipment is specifically calibrated at different levels for different elements, and as such provides a high degree of accuracy for each element examined. An analysis for ten wear metals would therefore require ten passes through the equipment. This procedure provides the greatest level of accuracy per metal analyzed, but it is time consuming. Some time can be saved by running several dozen oil samples for a specific element and then changing the equipment to the next element. Some labs run so many samples that they can provide same day service on a routine basis.

Wear metals analysis (emission spectroscopy). In this procedure a small oil sample is also burned but the detection device measures the different levels of light emitted.

The equipment is calibrated to simultaneously measure the emitted light from as many as 18 different wear metals and contaminants. In little more than a minute a complete metals analysis can be completed, with accuracy to within several parts-per-million. This procedure provides somewhat less accuracy than atomic absorption, but it can be completed much more quickly. It can be particularly effective in monitoring trends in wear metal levels for GTE.

Spectrographic metals analysis is usually the 'heart' of most oil analysis programs. Using either a Rotrode Emission Spectrometer or an Inductively Coupled Plasma (ICP) Spectrometer, 20 or more metals can be simultaneously determined. The metals analyzed for include wear, additive, and contaminant metals and are reported in parts per million (ppm).

The Rotrode Spectrometer has a particle size detection limitation of between 3 and 10 μ (depending on the particular metal in question and the amount of surface oxidation on the particle surface) compared to the 5 – 2 μ limitation of the ICP. Results of the Rotrode Spectrometer are accurate to about 1 or 2 ppm. Results of the ICP are accurate to 1 ppm.

The advantage of the Rotrode Spectrometer is that no dilution of the sample is required, while the advantage of the ICP is its accuracy. With proper sample preparation, an ICP can measure in the 10's of parts per billion (ppb). Particle size limitations of an ICP are even more sever than a Rotrode Spectrometer because the sample and particles have to be nebulized. If measuring very low concentrations, the diluent (usually diesel fuel) has to be at least as clean.

For routine lube oil analysis, accuracy below the 1 ppm level is not required. The results are very trendable from sample to sample if the sampling interval doesn't exceed every three months and proper sampling procedures are adhered to.

Periodic engine oil analysis is an important element in extending oil drain intervals and prolonging engine life. Rising prices for motor oils and questions of future availability have made it increasingly important to extend oil drain intervals whenever possible. Periodic analysis is the only reliable method to determine exactly when the oil needs to be changed. In addition, analysis of the types and levels of contamination can identify potential engine problems before they become serious enough to cause downtime and major repairs

However the approaches, offered till now, of a complex diagnosing problem solution did not consider change of an engine gasodynamical stability reserve.

Problem statement

For GTE technical condition diagnosing on the basis of the wear products in oil accumulation analysis, oil tests are basic information carriers.

Analysis of the types and levels of wear metals can be used to determine which engine components are wearing and if the level of wear is becoming critical.

Most tests measure levels of iron and aluminum to determine the amount of wear in piston rings and cylinder walls.

High levels of cooper, lead and tin are indications of main bearing wear and represent a more serious problem. Some tests also determine the level of silicon as a measure of ingested dirt or dust, the levels of lubricant additives and the levels of sodium or boron which indicate contamination from antifreeze.

In some instances this information has made the difference between minor component repairs and major engine overhauls. Often there is a distinct correlation between contamination or additive depletion and increased wear metal content, making it relatively easy to not only isolate the problem, but recommend specific action as well. Analytical techniques include atomic absorption, emission spectroscopy and Ferrographic analysis, with each technique offering a slightly different perspective on wear metals.

Timing is a critical element in any oil analysis program.

An oil sample indicates the condition of the bulk operating oil and GTE at the time that it was taken. Since operating conditions change, the longer an oil sample sits before being analyzed, the less pertinent the data will be. An equally important timing decision is determining when individual systems are to be sampled, and it is this aspect of timing that provides the most debate between operations and oil analysis specialists.

There are three fundamental techniques to determine oil analysis sample intervals:

1) sampling when a problem is suspected;
2) analysis on a "spot check" basis;
3) trendline analysis.

Each technique has its supporters, though not surprisingly, most decisions are ultimately made on cost.

Perhaps the most widely used technique is to sample only when a problem is suspected. The operator may detect excessive noise or vibration, experience a decrease in system performance, or notice changes in the color or odor of the oil. Some experienced equipment operators contend that this type of monitoring catches most serious problems, but most admit that it is not foolproof. Even though it is the least expensive of the three, it does require an experienced operator, and one that has learned how to detect minor variations in system performance.

Those oil tests are periodically taken at certain places (points) of a power plant, according to the developed technology for each particular engine type.

The fundamental purpose of oil analysis is to generate information about the condition of the oil and GTE it is being used in.

This information can then be used to reduce unscheduled equipment downtime, extend oil drain intervals, or increase equipment life. It is this final part, the conversion of analytical data into valuable operating information, that is the most subjective and controversial.

Vibro-speed gauges are used for vibro-overload factors determination.

Other methods are not applied because of many reasons. For example, disadvantages of diagnosing methods, on the basis of thermogasodynamical parameters measurement are an illegibility of engine gasodynamicaly imitated modes identification, on which diagnosing is carried out, and also an insufficient controllability level of modern GTE.

On the base of above-stated, authors offer the complex diagnosing technique, where diagnostic parameters are relative iron in oil concentration increment factor, an engine general vibration parameter, a critical element damageability level and relative value of GTE compressor gasodynamical stability reserve, that integrally characterizing an engine flowing part condition.

The relative stability reserve factor can be determined by following formula:

$$\Delta\overline{K}_{st} = \frac{K_{st.CON}}{K_{st.O}} - 1,$$

where $K_{st.CON}, K_{st.O}$ are initial and current value of compressor stability reserve, respectively.

Values $K_{st.CON}, K_{st.O}$, as parts of equation (1), are determined by a method described in work [7].

Use of the listed diagnostic parameters suitable for cycled work program of GTE, i.e. for standard flight.

If execution differs from one flight to another, that takes place in real conditions of operation it is necessary to use, as diagnostic parameters, speed of accumulation of critical element damages accumulation speed during *j*-s flight $\frac{\delta\Pi_j}{\delta_{f_j}} t_{fj}$ [8], and also iron in oil concentration factors relative increments, $\frac{\Delta K_{f_t}}{t_{fj}}$, vibrations $\Delta\overline{K}_v \frac{j}{t_{fj}}$ and gasodynamical stability $\Delta\overline{K}_{st} \frac{j}{t_{fj}}$.

On the basis of operational data correlation and regression analysis it is possible to establish statistical dependences:

$$\begin{aligned}
\lambda_0 &= A_0 + \frac{1}{t_{fj}}[A_1\delta\Pi_j + A_2(\Delta\overline{K}_{Fe})_j + \\
&+ A_3(\Delta\overline{K}_V)_j + A_4(\Delta\overline{K}_{st})_j];\\
\lambda_1 &= B_0 + \frac{1}{t_{fj}}[B_1\delta\Pi_j + B_2(\Delta\overline{K}_{Fe})_j + \\
&+ B_3(\Delta\overline{K}_V)_j + B_4(\Delta\overline{K}_{st})_j];\\
\psi_0 &= C_0 + \frac{1}{t_{fj}}[C_1\delta\Pi_j + C_2(\Delta\overline{K}_{Fe})_j + \\
&+ C_3(\Delta\overline{K}_V)_j + C_4(\Delta\overline{K}_{st})_j]; \qquad (2)\\
\psi_1 &= D_0 + \frac{1}{t_{fj}}[D_1\delta\Pi_j + D_2(\Delta\overline{K}_{Fe})_j + \\
&+ D_3(\Delta\overline{K}_V)_j + D_4(\Delta\overline{K}_{st})_j];\\
\gamma_0 &= L_0 + \frac{1}{t_{fj}}[L_1\delta\Pi_j + L_2(\Delta\overline{K}_{Fe})_j + \\
&+ L_3(\Delta\overline{K}_V)_j + L_4(\Delta\overline{K}_{st})_j];\\
\gamma_1 &= M_0 + \frac{1}{t_{fj}}[M_1\delta\Pi_j + M_2(\Delta\overline{K}_{Fe})_j + \\
&+ M_3(\Delta\overline{K}_V)_j + M_4(\Delta\overline{K}_{st})_j];
\end{aligned}$$

where $\lambda_0, \lambda_1, \psi_0, \psi_1, \gamma_0, \gamma_1$ are the factors describing an engine conditional damageability;

$A_0 ..., A_4; B_0 ..., B_4; C_0 ..., C_4; D_0 ..., D_4; L_0 ..., L_4;$ $M_0 ..., M_4$ are constant factors of regress lines equations

After equations (2) left parts solution, it is possible to determine an equivalent operating time:

$$t_e = \frac{\overline{K}_\tau - \Delta\overline{K}_{Ft}\lambda_0 - \Delta\overline{K}_V\psi_0 - \Delta\overline{K}_{st}\gamma_0}{1/\tau_e + \Delta\overline{K}_{Fe}\lambda_1 + \Delta\overline{K}_V\psi_1 + \Delta\overline{K}_{st}\gamma_1}.$$

For known conditional damageability we shall determine residual durability

$$\tau_{oct} = \sum_{j=1}^{j=k}\sum_{i=1}^{i=z} t_{ij}\left[\frac{1}{\delta(\overline{K}_\tau, \Delta\overline{K}_{Fe}, \Delta\overline{K}_V, \Delta\overline{K}_{st})} - 1\right],$$

where $\delta = \frac{1}{\tau_e} t_e$.

For determination of conditional damageability the likelihood method considered in work [9] is used.

Conclusions

The offered complex method of diagnosing is suitable for airlines, that are using aircrafts or helicopters with GTE, which have an operating time allowing authentically define dependence between constant factors and relative increments of diagnostic parameters with use of statistical data.

References

1. *Александров В.Г.* Контроль технической исправности самолетов и вертолетов. – М.: Транспорт, 1976. – 360 с.

2. *Ямпольский В.И., Белоконь Н.И., Пилипосян Б.И.* Контроль и диагностирование гражданской авиационной техники. – М.: Транспорт, 1990. – 182 с.

3. *Сиротин Н.Н., Коровкин Ю.М.* Техническая диагностика авиационных газотурбинных двигателей. – М.: Машиностроение, 1979. – 272 с.

4. *Ахмедзянов А.М., Дубравский Н.Г., Тунаков А.П.* Диагностика состояния ВРД по термогазодинамическим параметрам. – М.: Машиностроение, 1983. – 206 с.

5. *Волянська Л.Г., Панін В.В., Гаоюн Сунь.* Методи і засоби підвищення газодинамічної стійкості компресорів газотурбінних двигунів. – К.: НАУ, 2005. – 200 с.

6. *Программный* комплекс для эксплуатационного мониторинга выработки ресурса основных деталей авиационного двигателя Д-18Т / Д.Ф. Симбирский, А.В. Олейник, В.А. Филяев и др. //Авіаційно-космічна техніка і технологія. – Х.: НАКУ "ХАІ". – 2004. – Вип. 7/15. – С. 145–150.

7. *Янко А.К.* Определение остаточного ресурса ГТД на основе анализа изменения запасов прочности наиболее нагруженных элементов// Промышленная теплотехника. – К.: Наук. думка. – 1980. – №4. – С. 86.

8. *Деклараційний* патент на корисну модель МПК7GDI№3/00 Спосіб оцінки запасу газодинамічної стійкості компресора газотурбінних двигунів в умовах експлуатації / Л.Г. Волянська, І.Ф. Кінащук, Ф.І. Кірчу, В.В. Панін. – Опуб. 17.04.06. Бюл. №4.

9. *Лапшов В.Ф.* Основы управления техническим состоянием авиационных газотурбинных двигателей в эксплуатации. – К.: КИИГА, 1989. – 108 с.

The editors received the article on 26 September 2006.