DIAGNOSTICS OF RD-33 ENGINES

Ján Kabát – Peter Krajňák

The article is dealing with the diagnostics of the RD-33 aviation turbojet engine. The focus is on the description of actual state of diagnostics of the engine by the SDK-88 system and in the description of the detection of failures, such as intake of foreign objects, presence of impurities inoil and engine vibration during operation.

K e y w o r d s: diagnostics of the turbojet engine, impurities in oil, engine vibrations.

1 INTRODUCTION

Reliability of aviation equipment and efficiency of operation is increased by timely identification of errors and failures in the process of technical servicing. Diagnostics forms inseparable part of these programmes.

It enables detection of failures already in the initial stage of development and their subsequent quick elimination. Diagnostics enables operation of aviation equipment and aviation engines in line with their technical status and thus the reduction of the number of the maintenance staff and costs of repair.

Great attention is paid to theory and practice of diagnostics resulting in the development of universal methods of diagnostics and tools as well as their highly efficient applications.

2. ACTUAL STATE OF DIAGNOSTICS OF THE RD-33 ENGINE

The RD-33 aviation engine is a bypass, two-shaft turbojet engine with low bypass ratio, mixing airstreams before the afterburner. Together with the KSA gearbox and the GTDE-117 turbostarter it makes up the power plant of the MiG-29 fighter. Diagnostics of the engine systems and its electrical equipment when in operation is laid down in the technical documentation.

Experiences from the operation and progress in various fields of diagnotics methods enable improving the reliability of originally series production RD-33 engines.

Diagnostics of the engine specified by the original technical documentation (version as of 1988) consisted in measuring engine parameters at engine runups on ground in line with the prescribed procedures, endoscopic checks of the air-gas compartments.

Innovation of the original diagnostics methods consisted in the introduction of:

- **Parametrical checks** by way of the system and the specific software making use of the flight parameter recordings of the TESTER-U3L-T system;
- **The SKD-88 system** to check electrical equipment of the engine and perform measurements of parameters at engine runups on ground;
- **Modern endoscopes**;
- **Prescribing individual intervals** for performing endoscopic check with due regard to the engine status.

1) Parametrical chcecks

Development of parametrical checks of the RD-33 aviation engine is characterized by cooperation of experts in the development and manufacturing and specialist for operation. Achieving synergy of the basis of knowledge and experiences of the separate groups of specialists resulted in establishing a theorecial basis, devloping an algorithm of parametrical checks, to be then verified in operation, fine-tuning, further monitoring of the efficiency of the algorithms, their information outputs and subsequent development of annexes and changes the technical documentation.

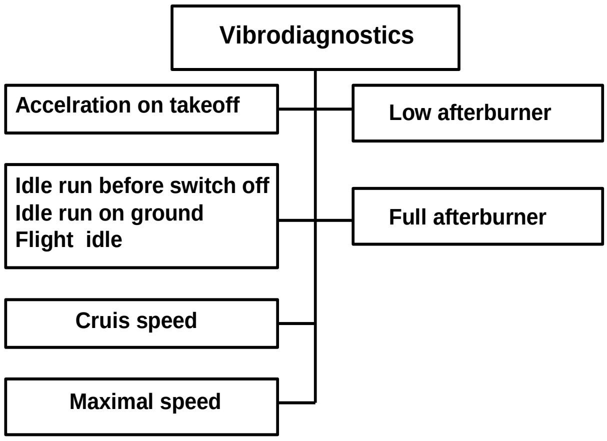
The analyses performed during remedy actions on the RD-33 engine concluded that the critical parts for potential damages are those subjected to high temperatures.

Damages to the "hot" parts of the engine lead to direct destruction of the engine. The process of the damages of „hot" parts develop „rapidly", which in operation may lead to the destruction of the engine within 1 hour of engine operation after the damage has started to develop.

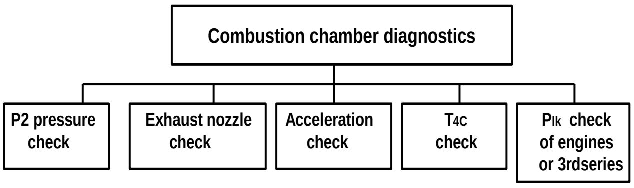
Analyzes of the parameters recorded by the TESTER system have revealed the direct proportionality of the characteristics of gradual changes (drop, growth) to some of the parameters and development of damages on parts subjected to high temperature loads after carrying out several subsequent flights. In this regard, one of the main goals is the extension of parametrical chcecks on the RD-33 engine to the temperature of gases behind the gas turbine t_{4c}.

2) The SKD-88 system

The SKD-88 system is a unified system of checking of the power plant made up of the operators stand (rugged portable computer featuring a special-purpose software), block of transducers of signals from the transmitters placed on the engine and a block of imitation, generating stimuli for the electrical system of the RD-33 engine.



a)



b)

Fig. 1: Structure of parametrical checks on the RD-33 eninge in the specific software a) vibrodiagnostics, b) combustion chamber diagnostics.

Digital processing of the parameters with the SKD-88 enables issuing various protocols in textual formate at each measurement, their archivation, repeated presentation and thereby adding new tools of processing and analyses to specialists performing checks and diagnostics of the RD-33 and KSA systems. The SKD-88 is substantially improving precision, speed, objectivity and scope of measurements at engine runups and checking the BPR-88, BPK-88, APD-88 blocks. Engine runup is shorte by 30 % compared to the original technology.

3. CHECKING PARAMETERS DURING OPERATION

The measured parameters checked in operation of modern engines have three levels of information:

- ***display in the cockpit*** – showing the data of the most important parameters, knowledge of which is necessary for proper servicing of the aircraft (e.g. engine vibraitons). On reaching the limit values additional light or audio signals are activated.
- ***recording aboard the aircraft*** – substantial amount of information is recorded and stored aboard of the aircraft flight data recording equipment.
- ***ground checks*** – revealing a great number of diagnostics symptoms when checked by ground personnel (visual checks, checking filters etc.)

The diagnostic center, a team of specialists having analysed the incoming information is making the decision based on the results of the analysis and comparisons with the previous values wether to continue the normal operation, perform additional checks, replace of a part, block or ban the engine from operation.

Tests of aviation engines have shown that the greatest damages, particullary those inflicted to hot parts, occure at the heaviest (maximal) mode of operation. Damages to the air-gas duct of the compressor occure during takeoff or landing of the aircraft.

Analyses of the engine failures of power plants withdrawn from operation and sent back to repair shops have shown seven typical failures:

- Intake of foreing objects,
- Burning the turbine blades,
- Damages to fuel ramp,
- Oil consumption,
- Engine rotor blocking,
- Vibrations exceeding allowable limits,
- Damages to compressor blades.

On the basis of damages in the process of engine tuning and its series production, some structureal changes have been adopted in order to improve reliability. With the increased use of the engine in operation and extending the mean time between repairs, typical failures involved intake of foreign objects, using up oil and vibrations.

1) Penetration of foreign objects

In operation, this is usually detected visually with endoscopes and increased level of vibrations compared to the previous flight. Visual checks can only reveal apparent defects on the working blades of the rotors in the forms of cracks, depressions, deformations, and splits.

- <u>Detection with endoscopes</u> – is used to assess the status of parts and assembly units of the bypass duct. Such endoscopes feature good resolution and are equipped with instuments enabling non-destruction diagnostics of defects. Changes in the parameters of the operating mode enables highly sensitive detection of the symptoms and developing a map of engine failures at the damaged parts of the air-gas duct as far as to the structural node.
- <u>Detection using artificial intelligence and identification of images</u> – adapted mathematical model of the engine operation process enables computing concrete parameters of rotating engines in their typical cross-sections thereby acquiring thermodynamical parameters, too. Based on computer simulations and using the data recorded in steady operation of the engine, one is able to obtain a represntative sample for various states of the air-gas duct, with operational status included.
- <u>Detection using capacity sensors</u> - is one of the prospective methods of checking the air-gas duct of the engine. Fitting capacity sensors onto the engine when operated on ground enables reliable diagnostics of the technical status of each blade

including the radial play between the blade edge and the rotor caseing or the wheel, by way of detecting changes in the forms of frequencies, blade vibrations depending on the initial status obtained at the manufacturing or repair of the engine.

2) Impurities in oil, oil consumption

The most frequent failure to the oil delivery system of the engine is oil consumption. Diagnostics of the technical status of an engine in operation is currently performed in three ways:

- Laboratory spectral analysis of the particles of wear contained in the lubricating oil,
- Various types of indicators showing the presence of impurities in oil,
- Visual checks of filters and magnetic plugs.

Sealings of oil holes of bearing imbedding at aviation turbocompressor engines are designed so as to prevent oil leakage into the engine compartment. As a sealing material in contact sealings of all types of carbon-graphite rings aru sed. Checking the level of their wear is of high importance in every stage of the engine life-cycle (development, testing, operation). Status of labyrinth sealings can be successfully diagnosted in via spectral analysis of oil and for contact sealings – i.e. the carbon-graphite rings by way ferrogrpahy.

Ferrography – is a method based on magnetic sedimentation of metal particles of wear in the samples of lubricating oil from the operated engine, with the aim to define the type of wear, its intensity, modes of friction and lubrication. It is used during the research not only for ferromagnetic parts but also for those made of non-magnetic materials. Low-magnetic and non-magnetic materials, such as aluminium, bronze, brass, graphite etc. will also be included into the ferrogram as well as the micro-wear particles of magnetic materials, the presence of which is presumable from the the manufacturing process and the processes of friction and wear. In the vast majority of cases, aviation and engine oils do not contain metals typical for engine material structures. Metals in various aggregate states can be found in oil during its manufacturing, storage, transportation, or might be as products of contacts with damaged parts. Information carried by their concentration, such as the amount of copper, ferrum, titanium, tungsteen, aluminium, silicium, etc. will prevent formation of damage and reveal the general place of the its origin, or the need to have oil changed.

Another most frequent damage occuring in operation of engines is the fatigue – fragmentation of friction surfaces of roller bearings of geared transmissions. The process of fatigue-fragmentation at roller bearing friction and gear connections can be separated into three phases:

- Plastic deformation of the frinction surfaces,
- Development of cracks,
- Fatigue–fragmentation.

The moment when fatigue–fragmentation occurs can be determined by way of ferrographic analysis, when the filters show sediments of broken-off particles with typical shapes and proportionate sizes.

Finding snow-flake fluffy particles of wear on magnetic plugs, impurity indicators and filters with no trends of metal conentrations in the spectral analysis is also the criterion for the onset of such wear on the engine.

At screening the engine and taking oil samples from each support using the ferrographic and spectral analyser, one is capable of locating the place of defect directly on the part that should be replaced.

3) Engine vibrations

Currently, a highly efficient wy of checking the status of vibration in the intra-shaft, intra-rotor and other types of engine bearings are based on vibro-acoustical sensors. Checks are performed on a non-operating engine at manual cranking of the engine, with no sensor mounted on its body. It enables detection of the damage in the places of fragmentation, holes and cracks developed on the separtors, formation of roads of rolling bodies and their slippages. These instruments enable assessment only these damaged bearing without determining the initial stage of the defect. Current practice in the world of desing, a wide-band vibro-diagnostics is used. Its application with emphasis on the obtained results based on the specific frequencies of the parts is of positive effect in terms of the development of the methodology of research of the defect of „vibration“ when performing stand-based tests of the RD-33 engines. During the operation of the engine (as part of standard servicing) the existence of a pool of data on own frequencies of the parts and assembly parts, having them recorded on the vibration log-book of the spareparts for the contrete engine, makes it possible not only to monitor the changes of its states, but also precisely locate the defekt. Which need not show sypmptoms in the entire spectrum of vibrations, because its own frequency of vibrations of the parts changes when damage occurs. During the repair of the engine it has been frequently found out, that the technical status of the inseparable parts was satisfatory on the whole. They were found suitable for further use, but in view of the defficiencyies of the methodology for assessing their status, they were replaced by new ones. Results of the research and experimental works helped obtain a theoretical criterion of assessing the technicals status of the beraing. The diagnostic system enables determination of the technical status of bearings on the baseis of the measured value of the vibration amplitudes and make a qualified decision on its replacement in repair.

6. CONCLUSION

The methods of engine diagnostics detailed as above enable development of an algorithm of research in the causes of defects directly on the part. The methods are mutually supplementary and can be used not only for determining the defect but also its level and the methods of repair or remedy. A well equiped basis for engine diagnostics and a highly qualified staff is guarantee to the capability of locating the defect in their early stages of development. Recognition of defects in their premature stages of development followed by rapid replacement results in lower costs of repair and as high as to 100 % of engine maintenance by their technical status. Capability of checks and reparability of the RD-33 engines makes it also possible in the oprational conditions and centres or repair to recover operational capability of engines and removal of as much as 80% of defect by changing modules: fan, turbine rotor, compressor rotor, HPC rotor, combustion chamber, KSA, outlet duct, variable diameter nozzle. Without complete disassembly there can be diagnostics to eliminate allowable defects on operating blades of the fan and also alternate use for all the rotor blades of the high pressure compressor and turbine rotor. It enables repair of the damaged blades or their replacement directly on the engine and facilitate their further operation.

The work presented in this paper was supported by VEGA, Grant Agency of Ministry of Education and Academy of Science of Slovak Republic under Grant No. 1/0298/12 – “Digital control of complex systems with two degrees of freedom” and grant No. 1/1117/11 – “Integration of automatic flight control algorithms with control algorithms of aircraft turbocompressor engines”. The work presented in this paper was also supported by KEGA under Grant No. 018TUKE-4/2012 – “Progressive methods of education in the area of control and modeling of complex systems object oriented on aircraft turbo-compressor engines.

BIBLIOGRAPHY

[1] BIRGER, A - Nadeždnosť i kačestvo, Mežizdateľskaja serija, Technickaja diagnostika, Moskva "Mašinostrojenie" 1978.

[2] ŽERNAKOV, S. V. - Komplexnaja diagnostika kontroľ parametrov masliannoj sistemy GTD, Ufimskij gosudarstvennyj aviacionnyj techničeskij universitet

[3] ANTONOV, A.N.-MEŽZIL, E.K. - STRUKOV, A.A. - Uplotnenia masliannych polostej opor rotorov GTD. Doklad na pervom meždunarodnom simpoziume po transportnoj tribotechnike. "TRANSTRIBO 2001".

[4] STEPANOV, V.A.- KALAŠNIKOV, S.I.,. UGROMOV, V.S. - Primenenie ferrografičeskogo i rentgenospektraľnogo Metodov dľja diagnostiky techničeskogo sostojania abiacionnych turbocholodilnikov po soderžaniju časti iznosa v smazočnom masle,M. 1986. - C. 5-8. - (Tr. CIAM, № 1159).

[5] JUDIN, A.A. .STEPANOV, V.A. – Rekomendacii po normirobaniu kriteriev ocenki techničeskogo sostojania uzlov transmisii GTD po rezultatam spektraťnogo analyza masla

[6] STEPANOV, V.A. - Diagnostika techničeskoga sostojania uzlov transmisii GTD po parametram produktov iznosa v masle - "Saturn", Rybinsk, 2002, 231

[7] ELISEEV, J.S. "Diagnostika i vostanovlenie rabotosposobnosti aviacionnych GTD opraviť účinnosti turbínových motorov." .

[8] PANOV, V.A. - Diagnostika dvigatelej i ustranenie vyjavlennych defektov na meste bazirovania AT i v centrach ostanovlenia icpravnosti, MMP V.V. Černševa, Kafedra technologii izgotovlenia AD MAI.

AUTHORS´ ADDRESSES

Kabát Ján, Ing. PhD.
Faculty of Aeronautics
Technical university in Košice
Rampová 7, 041 21 Košice
e-mail: jan.kabat@tuke.sk

Krajňák Peter Ing. PhD
Air Base Sliač
e-mail: peter.krajnak.sl@gmail.com