Experience in application of eddy current technique for the inspection of D30-KU/KP/KU-154 aircraft engine disks during on-site maintenance

Maksim V. Vasilchuk - Main author[1], Alexander A. Elkes - Coauthor[1] , Yuriy A. Mikolaichuk - Coauthor[2], Oleg V. Kapshar - Coauthor[2] and Anton V. Opanasenko - Coauthor[3]

1. UEC-Saturn, Rybinsk, Russia - maksim.vasilchuk@uec-saturn.ru
2. GosNII GA, Moscow, Russia - mikol@ncplg.ru
3. Prompribor LLC, Moscow, Russia - ndt2@mail.ru

Abstract

This paper presents the results of eddy-current technology elaboration aimed at detection of fatigue cracks on the 1st stage low pressure (LP) compressor disk during on-site maintenance of D30-KP/KU/KU-154 engines.

The key idea of elaborated ET technique is the use of recurrent interfering signal from a structural element of the disk (sharp angle of the blade dovetail slot), which is sent to an eddy-current probe as a criterion that helps to determine correct positioning of the probe in a test area (on the disk face). In its turn, such correct positioning of the eddy-current probe installed in accordance with a specified amplitude level of the signal coming from the angle of dovetail slot, has enabled to detect minimum-sized fatigue cracks on the disk face.

1. Introduction

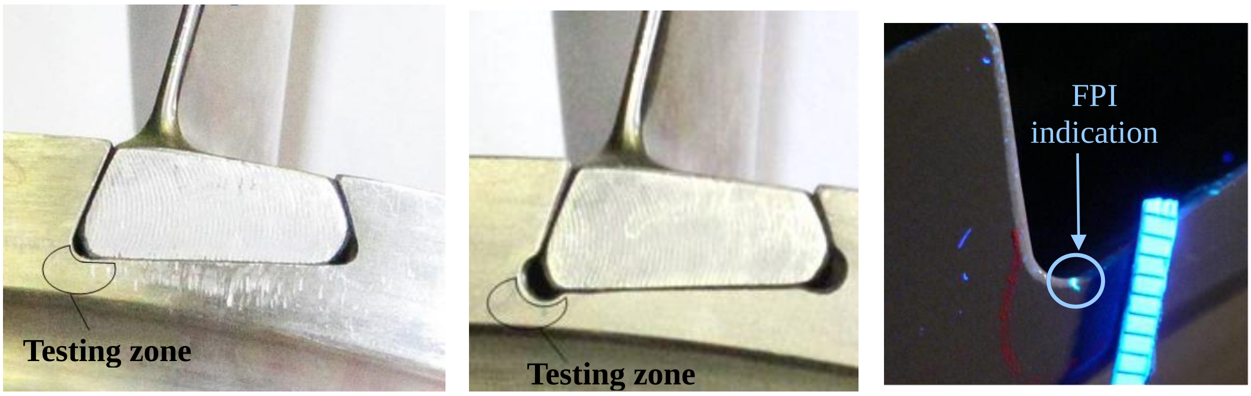
This paper presents the results of eddy-current technology elaboration aimed at detection of fatigue cracks on the 1st stage low pressure (LP) compressor disk during on-site maintenance of D30-KP/KU/KU-154 engines.

Topicality of this task is determined by the occurrence of non-localized disk disruptions due to uncontrollable crack growth.

2. Essential part

2.1 Problem statement

Operational reliability of aircraft engines is ensured by a set of measures, among which non-destructive testing (NDT) is one of the most important components. Thus, UEC-Saturn encountered a problem of detecting fatigue cracks that develop on the surface of fillets in dovetail slot angles of D30-KU/KP/KU-154 engine LP compressor, and break the disk face.



a) b) c)

a) – view of testing zone: disk before rebroaching;

b) – view of testing zone: disk after rebroaching;

c) view of a crack that breaks the rear disk face (FPI)

Figure 1. View of a test zone on the 1st stage LP compressor disk

In the initial phase of flaw detection, the most common testing techniques (endoscopic, ultrasonic) [1] had been used that, however, proved to be inefficient enough due to the failure to find cracks at their earlier stage of development, which resulted in the necessity to perform frequent inspections at short time intervals. Based on the residual life of the disk, UEC-Saturn announced a stringent requirement to the length of the cracks to be detected, which were propagating from the blade dovetail slot to the disk face. It was required to find cracks with the length of 0.6 mm.

Besides, UEC-Saturn imposed requirements on the applied NDT techniques to ensure the repeatability of test results, as well as the possibility of their recording and saving.

2.2 Principle and stages of developed procedure

To solve the problem, eddy current testing was chosen due to the fact that it met the basic requirements and had already been successfully applied at UEC-Saturn. This method was used for the inspection of the above mentioned LP compressor disk, to detect fatigue cracks on the surface of fillets in dovetail slot angles during maintenance of engines. VD3-81 EDDYCON eddy-current flaw detector, SVR-01 rotary scanner and rotary eddy current probe [2] were used for efficient solving of the above task.

In addition to the technical characteristics of the instrument which ensure the detection of cracks at their earlier stage of development, VD3-81 EDDYCON allows saving of settings and test results to the instrument’s memory, for further monitoring, remote data analysis and generation of test reports per each engine under inspection.

The versatility and multi-purpose functionality of the flaw detector, as well as positive experience of its use in different industries, including aerospace [3-5], contributed to the decision of UEC-Saturn experts in favor of this particular instrument.

Detection of fatigue cracks on the 1st stage LP compressor disk face was divided into the stages.

The first phase of eddy current testing of the 1st stage LP compressor disk was a selection of eddy current probe (hereinafter — ECP).

The scope of activities included a study of the differential probes with various configurations (shielded/non-shielded, with various ferrite core diameters and different types of protection against mechanical wear).

Investigations of the sensitive element of ECP included a number of scientific and practical works to determine:

a) correlation between the flaw detection amplitude and the distance of ECP from the flaw (Table 1, Graph 1);

b) influence of differential ECP angle on the crack detectability.

Determination of a correlation between the flaw detection amplitude and various distances of ECP center from the flaw

A graph of variance in the amplitude of a signal from a crack, depending on the distance of ECP center to the edge of an artificial flaw (AF), was plotted to determine the level of useful signal from AF, with its guaranteed intersection by the center of ECP.

The work was carried out using specialized devices that enabled to position the ECP in relation to the end of AF, with an accuracy of 0.1 mm.

The results are shown in Table 1 and Fig. 2:

Table 1. Results of determination of the correlation between the flaw detection amplitude and the distance of ECP from the flaw (Table 1, Fig. 2)

Distance from the end of AF to the center of ECP, mm	Signal from AF, mV
2.6	0
2.1	0
1.6	0
1.1	0.009
0.6	0.027
0.1	0.063
-0.3	0.073

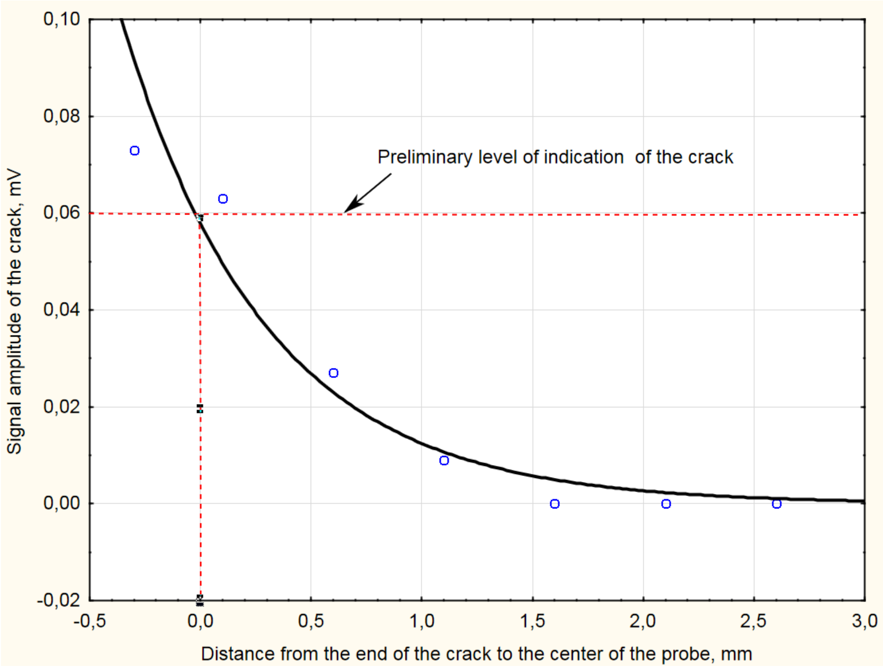


Figure 2. Curve of a signal from AF, when it is intersected by ECP center

Determination of an influence of differential ECP angle on the crack detectability

The influence of differential ECP angle on the crack detectability was determined in order to define the critical nature of this parameter during the inspection of a disk as part of an engine, since the probe was supposed to be installed at random.

The results are shown in Table 2.

Table 2. Results of detection of AF with different ECP angles relative to the test surface

Angle, °	Signal (upper loop/lower loop), mV
90	87/89
75	101/68
60	106/62
45	66/0
105	67/103
120	63/105
135	0/65

The results of the research showed that even a slight change in the angle of ECP (more than 5°) lead to a significant change in the test sensitivity (and re-distribution of the amplitudes of the lower and upper loops of the signal), so removal of such influence of the probe angle became one of the main technological problems that had to be solved during the design of the device, and the development of testing procedure.

Thus, the results of the research helped to determine a correct design of ECP and positioning tool for delivery of the probe to a test zone, taking into account the following factors:

- ensuring a stable angle of the probe in relation to the disk surface;
- ensuring a correct position of the probe on the disk, which would guarantee the intersection of a flaw by the probe.

The research resulted in the design of an optimized differential probe of SU3M5A4.5DD01 type.

The sensing element of the above ECP featured a conventional design: it incorporated two counter-connected measuring coils wound on D-shaped cores. The excitation coil was wound over the measuring coil. The external diameter of the sensing element was 2 mm. A non-shielded wear resistant sensing element was chosen when comparing the detectability of flaws. The research also showed that for the designed ECP, the required sensitivity to flaws in products made of VT3-1 titanium alloy was achieved at a frequency of 2.6 MHz.

After the design of the sensing element had been determined, during the second phase of works, a positioning tool was developed for 'blind' delivery of ECP into a test zone through a process hole, providing a reliable contact of the probe sensing element with a test surface, and positioning it in the longitudinal direction with an accuracy of 30 μm.

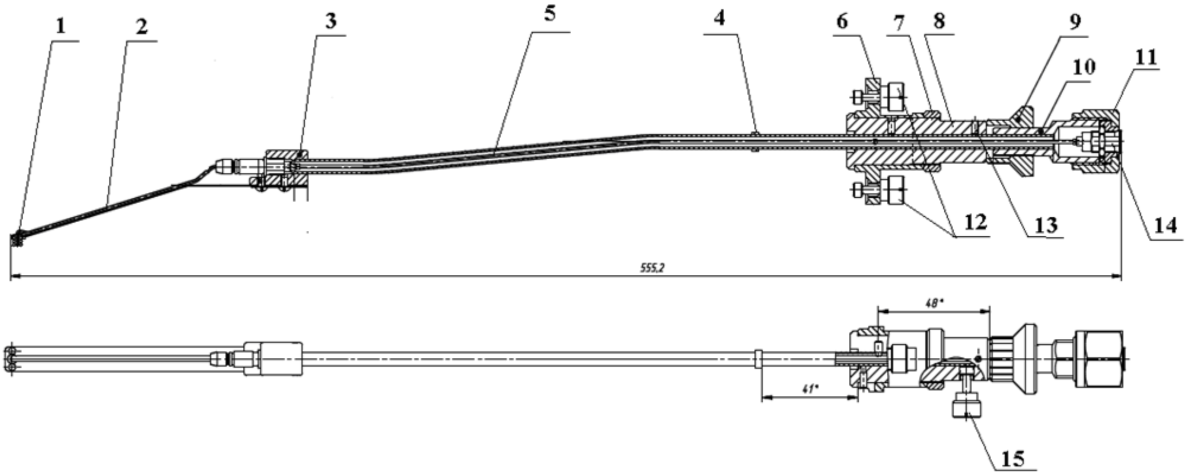
The third phase was devoted to elaboration of the procedure for eddy current inspection of the 1st stage LP compressor disk as part of D30-KU/KP/KU-154 engine during on-site maintenance, by the experts of Continued Airworthiness Center of the State Scientific Research Institute of Civil Aviation (GosNII GA), UEC-Saturn and PROMPRIBOR LLC.

Finally, the procedure was trial-tested under operating conditions and approved by UEC-Saturn, the designer of D30-KU/KP/KU-154 engine.

The key concept of elaborated ET technique was the use of recurrent interfering signal from a structural element of the disk (sharp angle of the blade dovetail slot), which was sent to an eddy-current probe as a criterion that helped to determine correct positioning of the probe in a test zone on the disk face. In its turn, such correct positioning of the eddy-current probe installed in accordance with a specified amplitude level of the signal coming from the angle of dovetail slot, enabled to detect target-sized fatigue cracks on the disk face.

2.3 Brief description of eddy current testing of the rear disk face of the 1st stage LP compressor.

For eddy current testing of the rear disk face of the 1st stage LP compressor, a special-purpose positioning tool is used that allows to place ECP in the engine, particularly, on the rear disk face. The positioning tool is schematically shown on Fig.3.



1 – ECP sensing element (differential coil); 2 – spring; 3 — adapter; 4 – stopper; 5 – tube; 6 – flange; 7 – nut; 8 – guide bush; 9 – adjusting nut with 16 divisions; 10 – adapter sleeve; 11 — swivel nut; 12 – screws to fasten flange 6 to inspection hole; 13 –retention screws (2 pcs.); 14 – Lemo connector; 15 – bush; 15 — locking screw.

Figure 3. Positioning tool for eddy current testing of the 1st stage LP compressor disk

SU3M5A4.5DD01 probe with an abrasion protection made in the form of a tungsten carbide insert is used for inspection, being mounted on a plate spring of the positioning tool. This probe provides the required sensitivity characteristics, along with a high wear resistance (up to 500 inspections). To increase wear resistance, the probe is additionally covered with Teflon tape.

Before placing ECP in the engine, it is required to carry out the following operations:

– geometry check of the positioning tool with ECP for the spring configuration, using specialized testing equipment;

– mechanical balancing of ECP using the testing equipment, which allows to place the sensing element perpendicular to the surface of a reference block (such position of the probe provides for a maximum test sensitivity);

– verification of the probe sensitivity in a balanced condition, using a reference block that has an artificial notch-like defect with the dimensions (depth x width) of 0.7x0.05 mm.

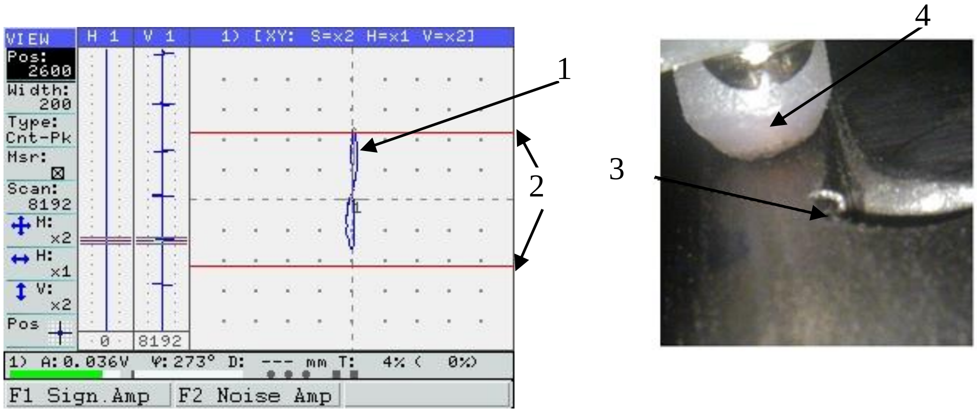
After that, the engine should be prepared for inspection of the 1st stage LP compressor disk in accordance with the testing procedure.

The probe is ‘blindly’ placed into the engine through a process hole, and then into a gap between the 1st stage disk and the housing of LP compressor front bearing, up to the flange stopper of the positioning tool, and further into the flange of the inspection hole located on the engine case. The flange of the positioning tool is screw-fastened on the flange of the process hole, and the probe does not come in contact with the disk face.

The positioning tool is designed in such a way that when installed in the engine through the process hole, the sensing element of the probe is pressed to the rear disk face of LP compressor.

Then, ECP is placed on the LP compressor disk face by rotating the adjusting nut of the positioning tool to evoke progressive movement of the probe. Moving in such a way, the probe is brought as close as possible to the dovetail slot angle. At the moment when the probe is approaching the dovetail slot angle, the disk is manually rotated (1 rpm) to arrest periodic signals coming from the dovetail slot angles (31 / revolution).

When the probe is approaching, the amplitude of a signal from the dovetail slot angles is increasing. As soon as the preset level of signals from the dovetail slot angles (the first trigger threshold) is achieved, which is monitored on the screen of the flaw detector, the probe stops moving (Figure 4). This preliminary setting serves to perform mechanical balancing of the probe placed on the disk in the testing zone.



a) b)

1 – signal from the dovetail slot angle; 2 – ALARM level to indicate that ECP has achieved a required position on the rear disk face; 3 – dovetail slot angle, from which signal 1 is coming, 4 – ECP.

Figure 4. Location of ECP on the disk when setting its correct position, where a) – view of the flaw detector screen at the maximum allowable approach of ECP to the dovetail slot angle on the rear disk face; b) – view of ECP on the disk face when setting its position (the photo was taken with the endoscope).

Further, by adjusting the movable parts of the positioning tool, mechanical balancing of ECP on the disk is performed, so that its axis is perpendicular to the surface of the rear disk face. In this position, the maximum sensitivity is obtained during testing.

The mechanical balancing of ECP is carried out in a static position of the disk as follows:

– ECP is manually removed from the surface of the disk being inspected, at a distance of ~5 mm. After that, the "Balance" key of the flaw detector is pressed in the air, and the probe is lowered to the surface of the disk being inspected, between the slots.

– The position of the indicator point on the flaw detector screen and the position of the time sweep lines along X and Y axes are estimated.

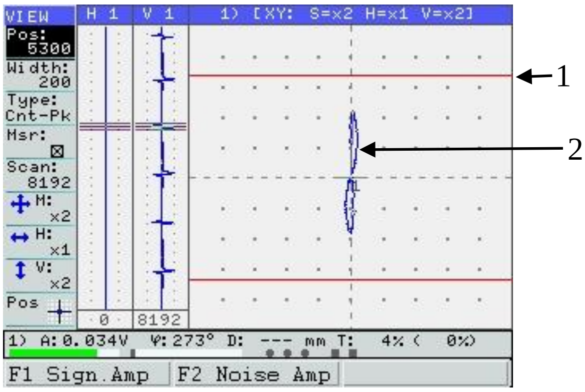
– If the indicator point has shifted from the center of the screen and the position of the time sweep line along Y axis has changed, an additional adjustment is to be made to ensure the position of the indicator point in the center of the screen, after which the position of ECP is fixed by means of the positioning tool.

The further position of the point in the center of the screen will indicate the correct position of ECP on the disk surface.

Then, one operator rotates the 1^{st} stage LP compressor rotor clockwise, using its blades, at a speed of one revolution per minute, while the other operator, by rotating the adjusting nut, smoothly moves the probe from the dovetail slots to the position on the disk face, in which the ALARM keeps triggering on one or several slots. While ECP is moving during the adjustment, the indicator point should not shift from the initial balanced position along Y axis, by more than 0.5 box of the scale division on the flaw detector screen.

Such configuration (with a balanced ECP) is final for testing.

To perform testing, the trigger threshold should be increased to the reject level. The reject level was established experimentally to detect a 0.6mm fatigue crack, against the signals coming from the dovetail slot angle on the rear disk face. In this case, the ratio of *“useful signal (from defect)/signal from slot (noise)”* is at least 2.



1 – ALARM level, 2 – signal from the disk slot

Figure 5. View of the flaw detector screen when setting the reject level and rotating the disk

One and a half to two clockwise revolutions of the rotor are required to obtain a guaranteed recording of signals from 31 slots. Mechanical balancing should be checked upon the completion of eddy current inspection of the disk.

If the signal exceeds the reject level, the engine should be removed from service. An example of such exceeding signal is shown on Fig. 6.

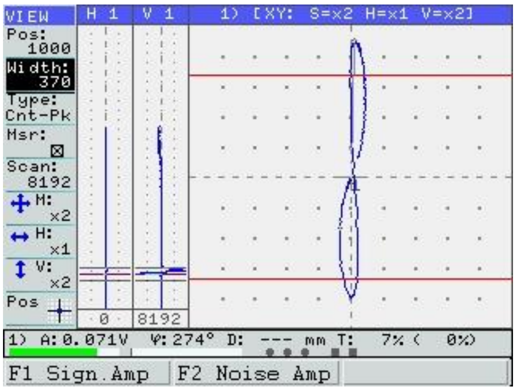


Figure 6. View of the flaw detector screen when detecting a 0.6mm-deep fatigue crack

The results should be presented in a dedicated Test Report and forwarded to UEC-Saturn.

3. Conclusions

Thus, to solve the task of detecting fatigue cracks on the rear disk face of the 1st stage LP compressor for D30-KU/KP/KU-154 engine, the following operations have been carried out:

1. As an instrument for eddy current inspection of the disk, VD3-81 EDDYCON flaw detector has been chosen, complete with a special-purpose eddy current probe of differential type. The appropriate settings have been selected to guarantee the detection of 0.6mm fatigue crack, against the signals coming from the dovetail slot angles, with a ratio over 2.

2. Adequate technological measures have been taken to ensure repeatability of the settings, steady position of the probe, as well as stable orientation of the probe axis in relation to the disk surface during inspection. Such measures mainly include:

– verification of the test sensitivity on a portable specimen with a reference notch;
– geometry evaluation of the positioning tool with a probe, using the reference equipment;
– mechanical balancing of the positioning tool with a probe, on the disk integrated in the engine.

The developed procedure was trial-tested under operating conditions, in order to estimate a statistical variability of the signals from the dovetail slots, based on which the position of eddy-current probe could be determined. During the trial, 138 engines were tested at the premises of three operator companies; 3 disks of the 1st stage LP compressor were rejected.

4. The operating procedure for eddy current inspection of the 1st stage LP compressor disk for Russian and foreign airlines has been developed and implemented.

5. A training film has been shot, so that the airlines can learn how to use the procedure.

Summary

At present, eddy current inspection of the 1st stage LP compressor disk using VD3-81 EDDYCON flaw detector is the main method of detecting cracks during on-site maintenance of D-30KP/KU/KU-154 engines. It is carried out by all airlines that utilize this type of engines.

Since the implementation of the procedure (year 2015), 924 on-site inspections of the disks have been performed on 527 engines, of which 3 disks of the 1st stage LP compressor have been rejected as defective.

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