DIAGNOSTICS OF DAMAGED COMPOSITE SKIN ZONES OF AIRCRAFT AFTER THE IMPACT OF LIGHTNING BOLT USING THE METHOD OF ACOUSTIC EMISSION

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Keywords: acoustic emission method, composite materials, lightning bolt

Abstract
The object of diagnostics is the Sukhoi Superjet 100 (RRJ) elevator. The elevator skin is made of 7-layer composite carbon-fibre-reinforced polymer. In the result of the test the load of lighting was determined as 110% of destructive load. It can be concluded that potential structural changes of composite material layers may occur in a much wider area than it is visually observable. The Acoustic Emission method (AE) is based on the register and analysis of acoustic waves occurring in the process of plastic deformation and destruction (crack growth) of the objects of diagnostics. The results of the research show that application of the AE testing method is a rational way for composite material non-destructive testing in civil aviation.

1. Applying the Acoustic Emission method for location of the composite elevator exfoliation in the places of a lightning bolt impact

The method of Acoustic Emission (AE) is based on the record and analysis of acoustic waves in the process of plastic deformation and destruction (crack growth) in the objects of diagnostics. For multiple layer composite material, of which the RRJ airplane elevator is made, this method allows to locate structural changes in the elevator's skin material being under impact of lightning bolt.

In case a lightning bolt affects an elevator, which skin is made of two 7-layer carbon composite panels there is a need to diagnose the material in the zones close to the place of visual destruction. Interestingly, the potential structural changes of layers of composite material could be located in a much wider zone than the observable damaged skin areas.

2. The object of diagnostics and equipment applied

2.1. The object of diagnostics

The object of diagnostics is the Sukhoi SuperJet (RRJ) elevator that is made of composite materials. The design of the elevator represents a 3-component cellular combination of 7-layer panels and cellular filler.

Before the tests on the AVIATEST LNK equipment the elevator has passed lightning bolt impact test certification according to the GSS (ГСС) program, p. 25.581

The destruction damage tests have been conducted in 2010. In the result of the tests, the failure load of elevator by a lightning bolt was identified and comprised 110% from the total failure load.

The exterior of the elevator after a static failure test is shown in figure 1.

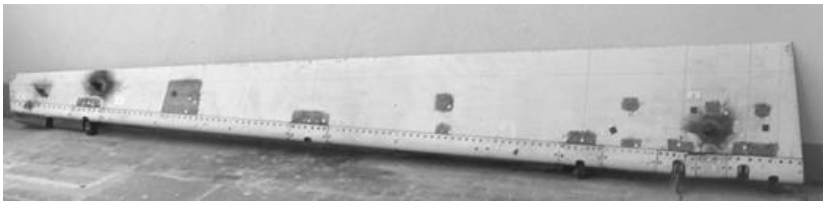

Figure 1. Elevator after the impact of a lightning bolt at the end of the static test.

The zones of a lightning bolt impact in the zone of the root and the tip parts are shown in figure 2. One impact spot is visible at the root segment and two at the tip (figure 3).

Figure 2. Root segment: cut zone PB1

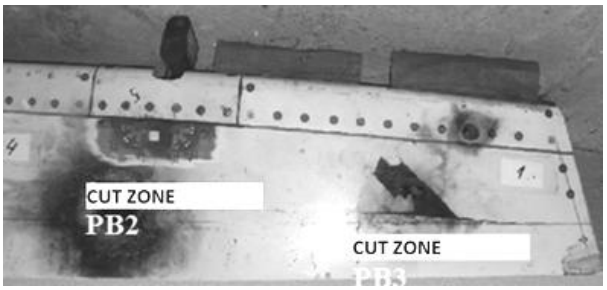

Figure 3.Tip segment: cut zone PB2, cut zone PB3

2.2. Equipment applied for the elevator diagnostics based on the Acoustic Emission method

The two-channel Physical Acoustics POCKET AE-2 portable unit was used for the test. Two piezo sensors were attached to the test surface. AEWin software was used for data record. The set-ups are shown in table 1.

Threshold	HFF	LFF	Preamplifirers	Sampling rate
30 dB	5 kHz	1000 kHz	Internal, 26dB	2 MSPS

Table 1. Measuring hardware settings.

The diagnostic assembly for the test using the AE is shown in figure 4.

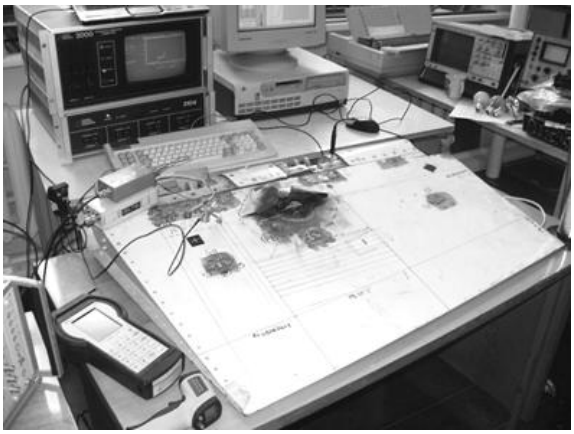

Figure 4. Assembly for elevator diagnostics using the AE method.

The attachment of piezo sensors to the surface of elevator's skin is shown in figure 5. For better relevance of the test results, a triple measurement recording was used (three independent sensors and measuring devices were used)

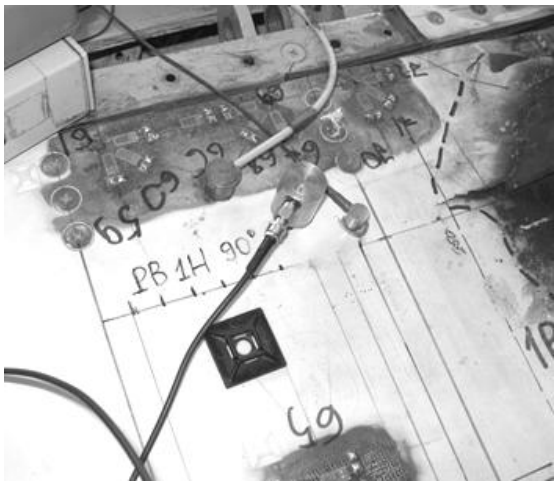

Figure 5. Attachment of piezo sensors' on the elevator's skin.

Schematic view of the triple recording of elevator fragment AE signal data is shown in figure 6.

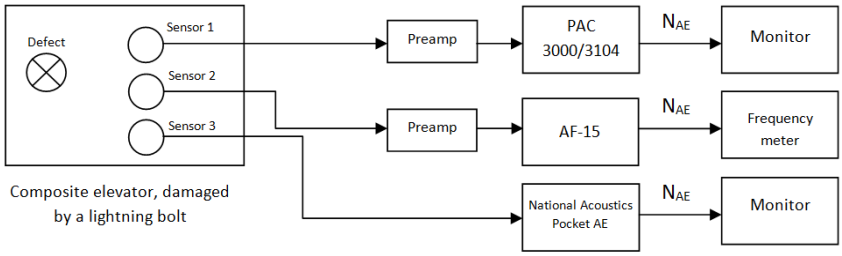

Figure 6. Schematic view of the AE measurements in the elevator's fragment

3. The results of elevator skin diagnostics in the areas of a lightning bolt impact

The research objects were the root zone (PB1, figure 2) and the tip zone (PB2, PB3, figure 3) of the elevator after the impact of a lightning bolt. The acoustic emission sensors were attached to the surface of the object. In the areas of diagnostics, the object was heated to the temperature of 80^0C. The atmosphere temperature was 24^0C. During the test, the heating element was sequentially attached to the surface from the impact zone center to the edges of the area. As the result, two zones of acoustic emission were located: faint in periphery and strong in the central zone. Zones of failure are shown in figure 7-9 (PB1, PB2, PB3 impact zones).

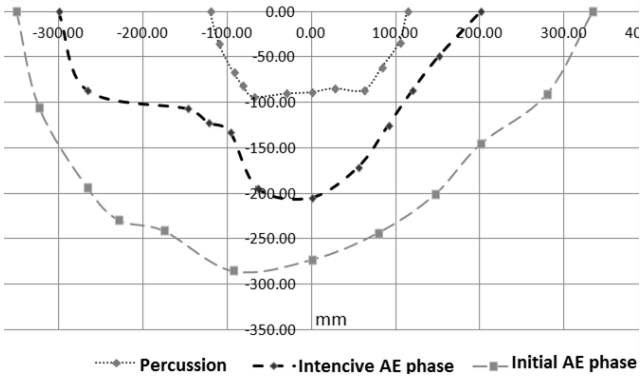

Figure 7. Diagnostics of the PB1 zone in the elevator's root area.

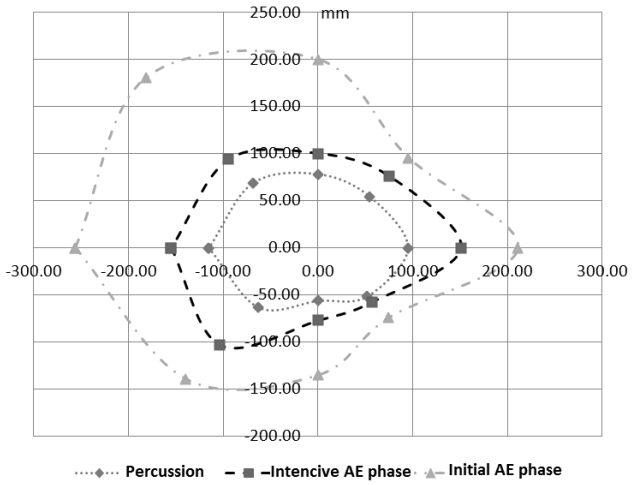

Figure 8. Diagnostics of the PB2 zone in the elevator's root area

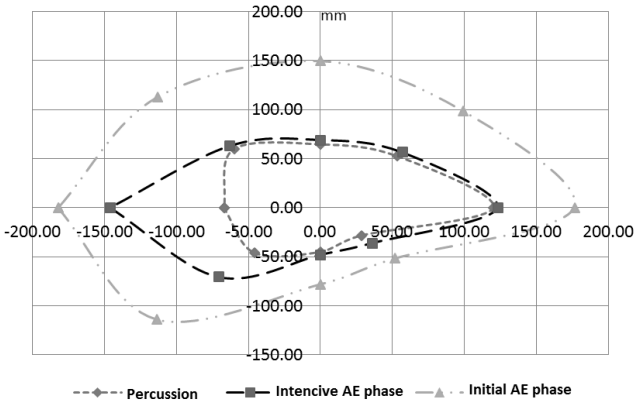

Figure 9. Diagnostics of the PB3 zone in the elevator's root area

The closest to the centre line shows the zone that is determined by the percussion method (tapping with a hammer). The second line – is the intensive evidence of failure (the AE method). The third line – shows the initial damage (the AE method)

Figure 10 shows the elevator's root area colored zones PB1: the central uncolored part is the material exfoliation in the process of percussion (AVIATEST); inner colorings are the noticeable AE zone; outer is the faint AE zone.

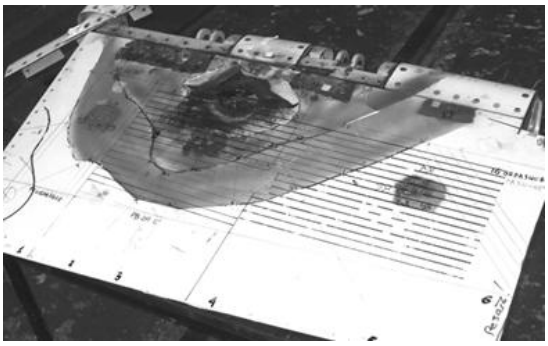

Figure 10. Elevator diagnostics zones (PB1)

In the process of elevator examination in the zones of a lightning bolt impact the following results have been obtained: diagnostics of structural changes in composite material of the elevator in the zones of a lightning bolt impact PB1, PB2 and PB3 was conducted; composite material structural change zones in the area of a lightning bolt impact were determined; the zone of fatal structural changes was determined by skin tapping around the impact area. It had an elliptic form (for the zone PB1) with dimensions 100x200 mm.

The zone of intensive and initial structural changes of composite material was determined by using the AE method (intensive AE zone is 350 by 500 mm)

In order to approve the results of diagnostics, strength tests of the skin samples in the zones PB1, PB2 and PB3 comparing to the properties of undamaged skin were conducted.

4. Stretch tests of the composite skin samples taken in the places of a lightning bolt impact

4.1. The research objects and equipment

Figure 11 shows samples that were cut from the elevator's cellular panel in the PB1 zone. Stretch-test samples had the size of 250x12 mm. Compression test samples were 85 by 12 mm. In addition, the stretch-tests of lower and upper skin panels of the 7-layer composite material were conducted. The above mentioned tests were highly significant because of the unequal damage of cellular interlayer samples in the places of attachment of testing machine.

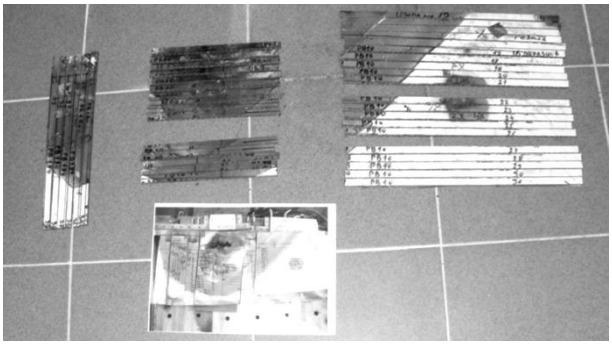

Figure 11. Samples cut from the elevator's cellular panel (zone PB1).

After cutting samples, zone coloring was preserved. The black color shows the most noticeable zone of damage, green shows the intensive structural change zone, orange is the initial damage zone. Samples were stretch-tested according to the standard GOST.

The character of destruction of a sample below the impact zone is shown in fig. 12.

Figure 12. The character of destruction of a sample below the impact zone

4.2. Stretch-test results of the elevator's additional samples

4.2.1. The character of destruction of the elevator's additional samples in the result of the stretch-tests additional

The kind and the place of failure of additional samples, taken from the elevator is shown in fig.13,14. The shape of destruction differs from the elevator's cellular-filled samples. The

destruction of additional samples generally occurs in the working zone without jamming the tip parts of samples.

Figure 13. Upper skin.

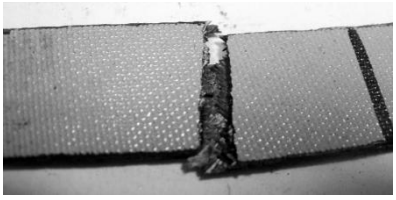

Figure 14. Lower skin. The form and place destruction of the elevator's additional composite samples in the result of stretch-test

The zone of intensive decline of the strength characteristics of lower and upper skins varies in the interval from 0 to 230 mm around the spot of a lightning bolt impact. Skin durability initial (faint) change zone is located 230 to 300 mm from the lightning bolt impact spot.

4.2.2. Determining the strength limits of mono-layers in the process of testing of additional samples in the lightning bolt impact zone

Figure 15 shows the strength limits (both for cellular-filling samples, and cut-out clean cells) depending on the distance between the sample area and a lightning bolt impact spot, distance to the spot of a lightning bolt impact.

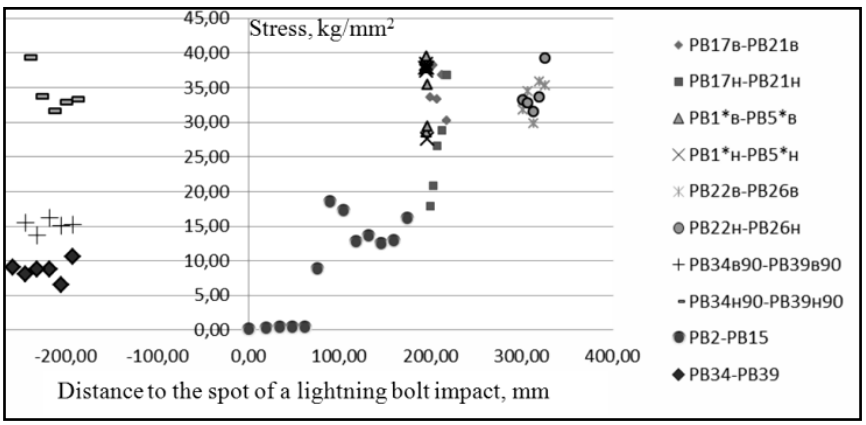

Figure 15. Strength limits of cellular-filling samples and additional samples depending on the distance to the spot of a lightning bolt impact.

The data in figure 15 shows that zone of intensive strength characteristics decline of the lower and upper skin varies in the interval between 0 and 230 mm around the lightning bolt impact. Zone of initial strength characteristics change is located 230 to 400 mm around the lightning bolt impact. The tensions in mono-layer are equal to the tensions in the process of stretching the sample, divided by the coefficient of volume part of fiber with 0 degrees packing (for the elevator this coefficient equals 3/7=0.4286). In the following tests tensions in the mono-layer KMKU-2.120.E01 are observed. Failure tensions in the mono-later KMKU lower and upper

panel samples PB1*-PB5* are located in the range of 80 to 86 kg/mm^2.Failure tensions of the upper panel samples are in the range of 40 to 86 kg/mm^2. Failure tensions of the lower panel samples are in the range of 40 to 86 kg/mm^2.

Conclusion

During the research, diagnostics of the SSJ-100 elevator's skin zones in the area of a lightning bolt impact using the Acoustic Emission method has been conducted. Zones of initial and intensive decline of strength characteristics of the elevator's skin have been determined. The area of significant structural damage has the elliptical form with the size 100 x 200 mm. The zone of structural changes of composite is defined by using the Acoustic Emission method. The zone has an elliptical shape, and comprises 350 x 500 mm in size.

The stretch- and stress-test results of samples' (laminate), taken in the zones of a lightning-bolt impact, have been demonstrated. The zone of the substantial damage of samples is located between 0 and 230 mm down and to the left from the impact spot. The limits of strength are between 0 and 40 kg/mm^2. The initial strength characteristics decline of the samples is observed in the zone of 230 to 400 mm from the spot of impact. The limits of strength in the zone between 230 to 300 mm from impact increased while increasing the distance from the impact spot between 40 and 85 kg/mm^2. For the upper-skin samples the limits of strength gradually increased from 70 to 93 kg/mm^2. For the samples that are cut with the 90 degrees angle, the limits of strength are 32-36 kg/mm^2, and for the lower skin sample– 40-65 kg/mm^2. The limits of strength when stress-tested are in the range of 40 to 63 kg/mm^2

An acceptable overlap of strength characteristics determined in the result of application of the AE method and the strength-testing of samples in the zone of a lightning bolt impact zone is observed. The obtained magnitudes of elasticity module for the mono-layer KMKU-2.123.E01 with 0 degrees package located in the range between 7200 and 900 kg/mm^2 that is less than the elasticity module magnitude, provided by the customer (13351.43 kg/mm^2). For the samples with 90 degrees cut, the elasticity module for KMU-2.12.E01 with 45 degrees package is in the range between 1500 to 2800 kg/mm^2.