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Experimental Stress Analysis

Verification of the strength of the composite propeller blade retention by means of strain-gauge measurement

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Abstract: The fitting of the composite blade in the propeller hub represents probably the most critical part of the propeller. Its sizing directly influences the weight characteristics of the propeller, operating reliability and safety of the entire design. The completed strain-gauge measurement confirmed the estimated sequence of failures in the overloaded node leading to the final fracture. It has also provided an interesting theme for possibilities of monitoring the design status during operation in the very part which is hard to inspect by conventional non-destructive methods.

Keywords: Analysis, FEM, Strain Gauge, Composite, Propeller, Blade

1. Introduction

Rotors work as accumulators of mechanical energy, so that potential critical failure of the blade may result in a fatal event for the entire work. For this reason, the retention of the composite blade must be designed so that the failure of the primary metal-composite joint was sufficiently secured by a safeguard which can itself provide for the transmission of the load with a sufficient allowance for the joint strength. Under normal operating conditions the properties of this safeguard must not deteriorate. Its function must be preserved on a long-term basis in the original quality.

Typical solution of the root part of the propeller blade is based on the transmission of the main operating loads from the composite to the metal parts via the adhesive joint which is secured by a shape lock. The fiber is led through the shape lock in such a way that it can only get disengaged from the lock by fracturing itself.

A large number of calculations and measurements have been performed at VZLÚ during the past years, at various types of shape locks; see [1]. One solution was chosen for further work, it was subjected to a detailed strain-gauge measurement on the composite and metal parts of the structure; for the sketch of the shape lock, see Fig. 2.

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Fig. 1. Study of a modern eight-blade VZLÚ propeller with composite blades.

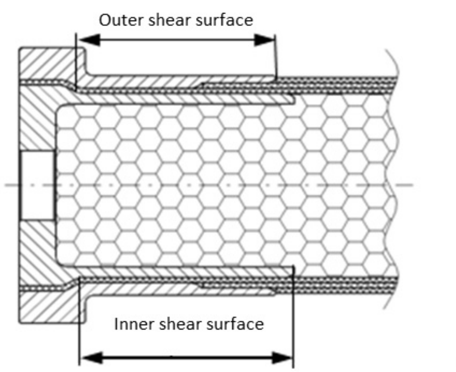

Fig. 2. Shape lock of the composite in the metal parts of the blade retention.

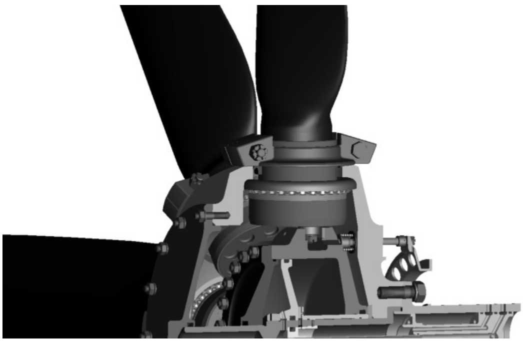

Fig. 3. Cross-section of CAD model of the typical design of the propeller hub with indicated type of the shape lock in the blade root.

Fig. 4. Test piece, "double-root" type, for testing the static strength of the joint.

Figure 3 illustrates a typical design of the propeller hub which makes use of the aforementioned shape lock in the blade design. The static strength of the propeller blade retention node is subsequently tested by means of the so-called "double-roots"; see Fig. 4. Identical retention node is formed at both ends of the cylindrical test piece made of composite; the node is exposed to a pure tension gradually all the way to the fracture; see Fig. 5.

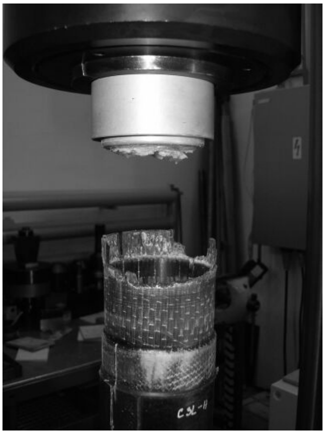

Fig. 5. Typical fracture of the double-root after the pull-out test. Fibers are evidently torn. The fracture usually appears at one end only, however the result has the valence of the test on two nodes.

Correctly performed sizing of the entire node is such which ensures that at the moment of the primary joint failure, i.e. the adhesive joint in the sliding surfaces as per Fig. 2, occurs before the plastic deformation is achieved at the metal parts. At the moment fiber fracture, the plasticization of some sections of metal parts is already permissible.

If the plastic deformation of metal parts does not occur at the moment of the fracture, it could mean that the metal parts are redundantly oversized and excessively heavy. On the contrary, any plastic deformation before achieving the shearing strength of the joint would reduce its lifetime and reliability.

2. Principle of joint failure

For operating characteristics of the test piece expressed as a function of the force applied on the shift of the tensile testing machine jaws, see Fig. 6. The indicated function is vital, because it enables to observe the development of the failure without the risk of premature breakage of the sample or the test suspension.

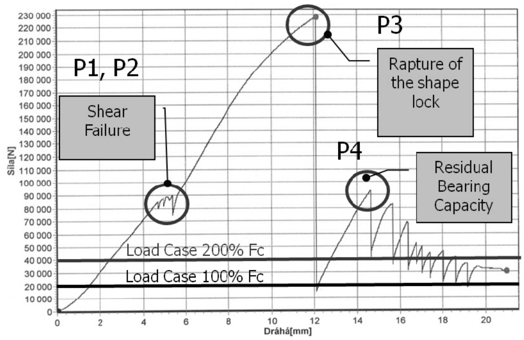

Fig. 6. Typical curve "Displacement vs. Force" of the "double-root" test piece.

Figure 6 highlights the significant events in the measured operating characteristics, marked as P1 to P4. Points P1 and P2 are ideally contiguous, while in reality they limit the interval of events connected with the shear fracture of the joints at both ends of the test piece; see the highlighted areas in Fig. 2. Point P1 is probably the initial shear fracture of the less strong node at one end of the test piece, whereas point P2 probably corresponds to the final shear fracture of the opposite node.

The area between points P2 and P3 corresponds to the loading imposed on the shape lock after the adhesive joint has lost its function. The load is not transmitted by the primary (adhesive) joint any more but by the safeguard in the form of the shape lock. In point P3 the fiber fracture takes place at the weaker end of the test piece, while the load imposed on the piece rapidly declines.

Since the test is designed as a test with controlled displacement and dependent allowance for the applied force it can be continued without interruption even in this state to observe the gradual repeated increase in the force above the Design load corresponding to 200% of the maximum Operating load. No sooner than in P4 load corresponding to approx. 450% of the maximum operating load (and of points P1 and P2) the composite starts to project out of the metal parts and the joints gradually starts to "jerk" until the composite fully protrudes from the metal parts; see Fig. 5.

The ratio of the Operating and Design load to points P1, P2 and P3 clearly indicates that the adhesive - primary joint alone is able to guarantee sufficient safety in the course of all estimated loads. If the primary joint fails, the shape lock still provides more than a double load capacity in comparison with the primary joint (ratio of P3 to P2).

3. FEM inspection

The performed finite element method (FEM) inspection confirms the concept of the load distribution between the primary joint and the safeguard in the form of the shape lock.

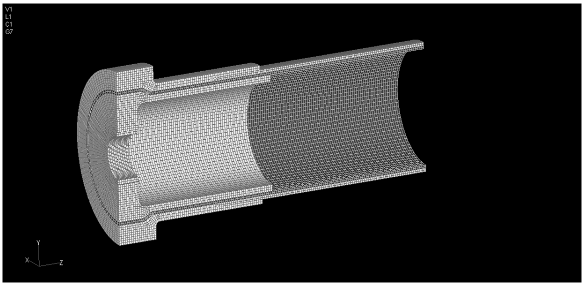

Fig. 7. Cross-section of the FEM model of the node design.

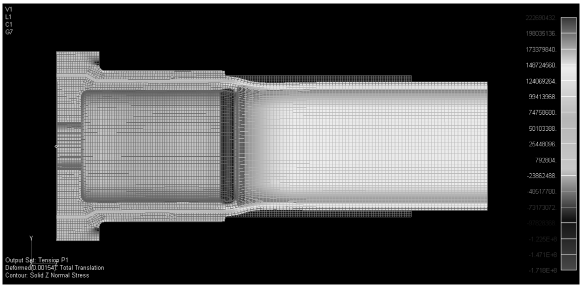

Fig. 8. Visualized shifts of the test piece under load. The color range corresponds to the normal stress component along the longitudinal axis (cylindrical coordinates).

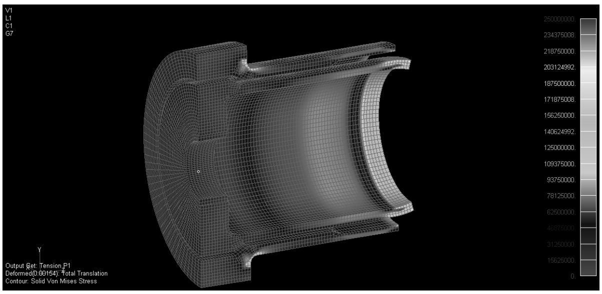

Fig. 9. Reduced stress as per the HMH (Von Mises) theory in metal parts at the moment of achieving the point P1.

Figure 9 plots the reduced stress as per the energy HMH theory in metal parts of the node at the moment of achieving the point P1. The calculation implies that the most stressed area is the edge of the inner metal part, which prevents the contraction of the cylindrical composite surface. On the other hand, the least stressed area is that of the shape lock (conical surface).

The ratio of lengths of the inner and outer metal part effectively prevents the laminate from peeling off the metal parts; see Fig. 8. Until the composite is separated from the metal parts, the shape lock remains unstressed and maintains all its properties during operation.

4. Strain-gauge measurement

Consideration and calculations concerning the distribution of stress and sequence of failures in the root part of the propeller blade are verified by a large set of strain-gauge measurements. For this purpose, the manufactured test pieces are fitted with strain gauges.

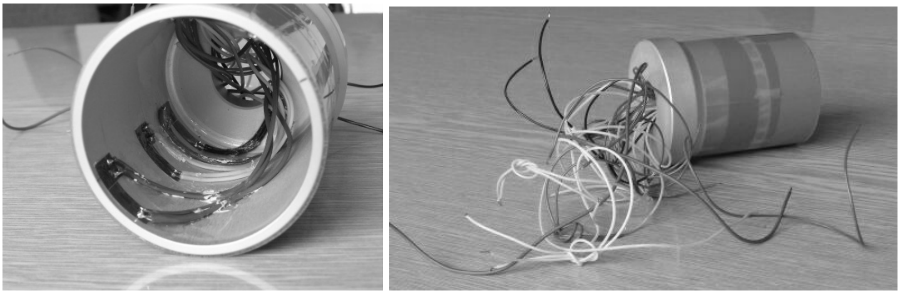

Fig. 10. The inner metal parts were furnished with strain gauges before the manufacture of the composite part (RTM process).

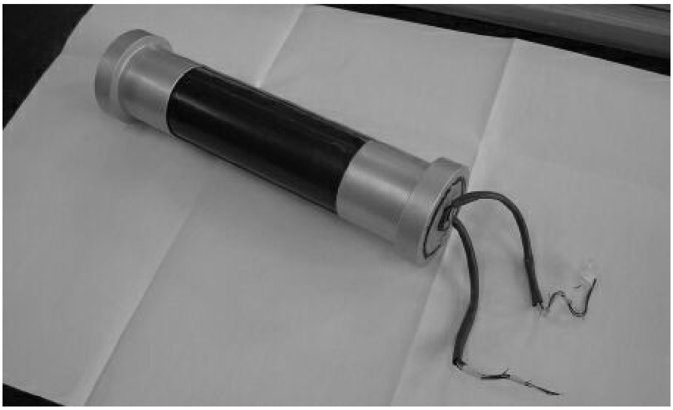

Fig. 11. Test piece manufactured with the use of the RTM technology, with ducts from strain gauges located on the inner surfaces of the metal parts.

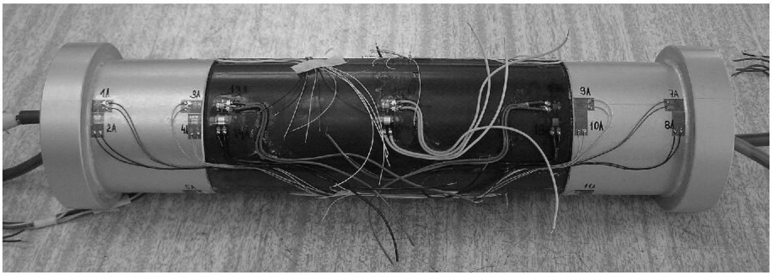

Fig. 12. Test piece completely fitted with 64 strain gauges.

The test piece fitted with 64 strain gauges (HBM 1,5/350LY43, HBM 3/350LY43, HBM 1,5/350LY41, HBM 3/350LY41) underwent load exposure with a gradual switching-over of the strain gauges. The load exposure was carried out repeatedly with un-stressing cycles, at first under the level of point P1, then under point P3 and then continuously until the complete fracture. The objective of the measurements was to confirm the occurrence of failures and their succession, and to obtain the initial data for the feed-back for FEM calculations.

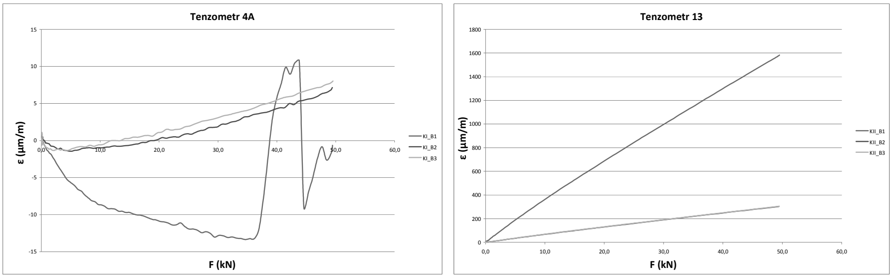

Fig. 13. Example of signal from the selected strain gauges in repeated load exposure. The first two cases were carried out before exceeding point P1, the last case corresponds to the state after the joint has been damaged due to exceeded P1.

Figure 13 illustrates an example of how signal changes at selected strain gauges before the failure is induced in point P1 and after failure. The failure itself was induced in different type of connection and is not covered by these records.

The progress of signals reveals a significant change which may be also used for the assessment of health monitoring during operation.

Another interesting finding is the considerable increase in the load capacity of the shape lock in comparison with the measurement referenced herein [1]. While point P1 of the first strain-gauged piece principally corresponds with the average value of the previously performed static tests of the entire series of test pieces without the strain gauge, point P3 has shifted upward by approximately 32%. This apparent reinforcement is attributed to the gradual disruption of the sliding surfaces, see Fig. 2, during repeated load exposure between points P2 and P3. The shock effect of sudden tear-off of the sliding surface before the shape lock is not included here, thus the fiber of the shape lock being distorted is stressed in point P3 more favorably in this case. This fact will be a subject of examination on further strain-gauged test pieces, which are currently being prepared for the tests.

5. Conclusion

The performed strain-gauge measurements confirmed the concept of the sequence of individual failures of the overloaded metal/composite joint in the propeller blade roots. Further tests will focus on pieces with a reduced number of strain gauges, the key point of these tests is to verify the repeatability of results and to complete the data file necessary for the creation of feed-back for the FEM calculations.

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References

[1] Pompe V., “Poruchy kořenové části kompozitních vrtulových listů,” (in Czech) in *Proceedings of Mechanika kompozitních materiálů a konstrukcí mk^2*, Prague, March 2008 (Czech Technical University in Prague, Faculty of Mechanical Engineering, Prague, 2008), pp. 13–23. ISBN 978-80-01-04044-7.