RESONANT FATIGUE TESTING OF FULL-SCALE COMPOSITE HELICOPTER ROTOR BLADES

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Abstract

Fatigue properties of composite materials are extremely important to design durable and reliable helicopter rotor blades. However, it is difficult to apply conventional fatigue test loads in a short period. Therefore, accelerating test speed and facilitating spectrum load realization are required. In this paper, a fatigue test method that uses a resonance of simply supported beam type blade specimen was introduced. This test consists in exciting the blade specimen with a frequency that corresponds to its natural frequency. In that case, the test specimen similar to a beam fixed between two pivot points starts vibrating and is significantly deformed. Resonant fatigue tests were performed by changing exciting vertical amplitude and frequency, and the S-N curves of each composite materials used in blade manufacturing were obtained successfully.

1 Introduction

Rotor blades are the representative flight safety parts that creates lift, thrust and control force needed for helicopter flight, and the composite materials were used for manufacturing blades after the 1980s. Composite materials were better than metal materials in terms of weight reduction and due to its superior ability of processing and fatigue tolerance, there are growing cases of applying fiber reinforced composites on not only blades, but other major flight safety parts as well.

The periodic aerodynamic change that occurs around the rotor blade during flight is applied as a repeated loading with high frequency features having a major impact on the blade's fatigue life. In addition, in order to qualify whether the life requirement is satisfied, it is necessary not only for structural analysis, but also to perform fatigue tests using the full-scale composite blades. The goal of the fatigue test is to check the critical area of the test part versus analysis results, and to determine the fatigue limit to be used for the blade retirement time or inspection interval calculation. As suggested in the rotorcraft's airworthiness regulations FAR-27/29[1,2] and the advisory circular AC-27/29[3,4], the fatigue evaluation of the composite blade can be conducted using the safe life, flaw tolerant safe life, or the fail safe methodology independently, or by combination of two or more of these[5]. Furthermore, for the blade specimen used for the fatigue test, several sectioned blade or the entire blade can be used. It is difficult to apply conventional fatigue test loads in a short period. Therefore, accelerating test speed and facilitating spectrum load realization are required. In this paper, a fatigue test method that uses a resonance of simply supported beam type blade specimen was introduced.

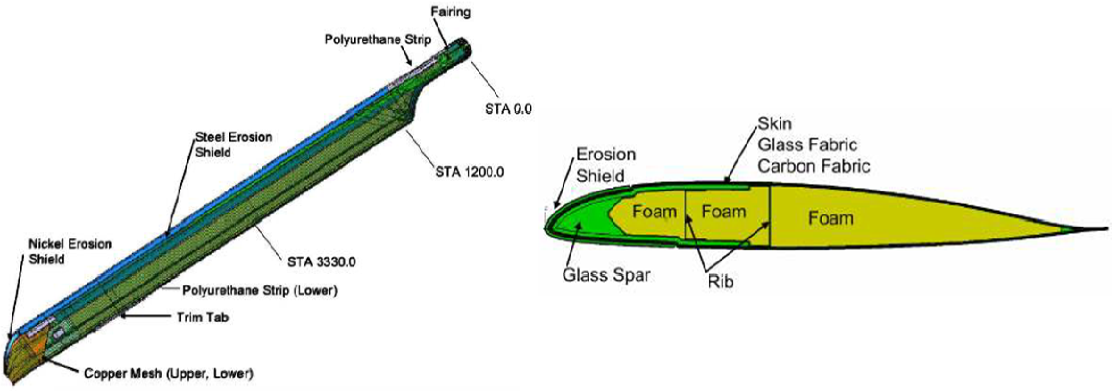

Figure 1. Internal components of composite blade

This test consists in exciting the blade specimen with a frequency that corresponds to its natural frequency.

2 Blade structures

The rotor blade is composed of the spar for supporting the centrifugal force that occurs when rotating, the flap moment and the lag moment, and the skin to configure the aerodynamic shape. In addition, it is also composed of deicing devices to remove the ice that is cumulated on the surface of the blade, and the protective devices to prevent damages caused by erosion due to sand and dust or damages caused by lightning. Typically, the reinforced glass and carbon fibers with epoxy resin matrix are used in the production of spar, torsion box and skin, while hard foam and honeycomb are used as core materials for layup and curing of the composite materials. Figure 1 shows the internal structures and the cross section of the helicopter blade.

The configuration of blade specimen was determined taking into consideration the geometric characteristics and internal structures, the properties of the composite materials, and the load distribution. The entire blade or sectioned blade can be used to perform the fatigue test. In this study, the fatigue test specimens were distinguished into attachment and airfoil section of main rotor blade. In the case of the root attachment component, centrifugal force, flap and lag moment have major impacts on the fatigue life. Also, for the airfoil section component, flap and lag moment have major impacts on the fatigue life.

3 Test method

In general, there are two options to realize the fatigue test load on blade specimens. First is the life test method that uses spectrum fatigue testing to verify the absence of growth over a large number of cycles that are equivalent to a lifetime of expected usage. This method utilizes one or more full-scale, component, or sub-component test specimens subjected to spectrum fatigue loading applied in a representative distribution of flight loads. Second is the S-N fatigue test method that is based on determining the point where crack initiation occurs. This method utilizes one or more full-scale, component, or sub-component test specimens subjected to constant amplitude or spectrum loading applied in a distribution on the structure that is representative of critical flight conditions. For S-N type test, the test static and dynamic loads are defined by mean fatigue curve in order to reach the failure about 1.0 M cycle. But, the test loads can be changed considering the test load frequency and the test period. If the fatigue failure is not occurred at the predicted cycle, the test will be performed to reach the failure with 10%~30% increased dynamic loads. In this study, the S-N type test method was applied to evaluate the fatigue life of composite blades. Furthermore, in order to generate fatigue failure on the blade specimen, a constant amplitude test load was repeatedly applied.

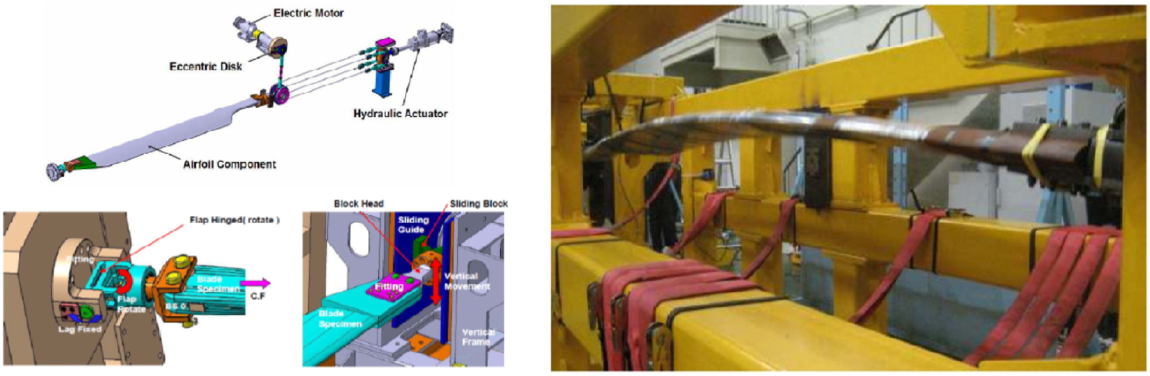

Figure 2. Configurations of fatigue test bench

In order to evaluate the fatigue properties in high cycle frequency region, it is normal to generate fatigue failure at levels of 10^6~10^9 cycles, and therefore, it requires a long period of testing. Thus, in order to more efficiently conduct fatigue tests, it is necessary to increase the speed of applying the test load.

The airfoil component fatigue test was performed by exciting the blade specimen with a frequency that corresponds to its natural frequency. In that case, the test part, similar to a beam fixed between two pivot points, starts vibrating and is significantly deformed. This test was performed with centrifugal force, flap and drag moment simultaneously by using a hydraulic actuator and electric motor. The centrifugal force is applied to the test specimen with steel cables, and the flap and lag moment is directly applied on the iron fitting of the test part with an eccentric disk. The moment ratio depends on the blade specimen setting angle into the test rig, and the blade specimen setting angle was determined when test load satisfies the previously defined flap moment and drag moment ratio. In this study, the centrifugal force was set so that the range of the exciting frequency would be between 4.5~5Hz. Methods for applying test loads using the resonance of the blade specimen are as shown in Figure 2.

When resonance is generated on the blade specimen through vertical excitation, the centrifugal force that must be maintained constantly in the blade's spanwise direction can change dynamically. However, in actual flight conditions, the change of the centrifugal force is small compared to the change of the dynamic change of the flap moment and lag moment that are applied on the blade. Thus, it is necessary to minimize the dynamic change of centrifugal force during the process of the fatigue test. In order to resolve such problems, accumulators were connected to the cylinder block of the hydraulic actuator so that it can take on the functions as a hydraulic damper. At the end of the test level or in case of damage, the residual strength proof test was performed to show that the structure, damaged or not, is able to withstand the ultimate loads. The static test loads were applied to the blade test specimen to acquire more than ultimate strain, and the catastrophic failure of blade test specimen was not detected.

4 Test load measurement

In order to measure the centrifugal force, a loadcell was used. Also, to measure the flap moment and lag moment applied to each cross section of the blade, full-bridge circuits composed of four strain gauges were used. In addition, all the strain gauges were wired before switching to the data acquisition system and the computerized data acquisition system can record and play of test data measured by the stain gages. Figure 3 shows the strain gages, flap and lag bridges attaching locations in chordwise direction.

Load calibration is needed to measure the flap and lag moments via the full-bridge circuit, and a strain gauge was attached on the position where the flag and lag moment were not coupled.

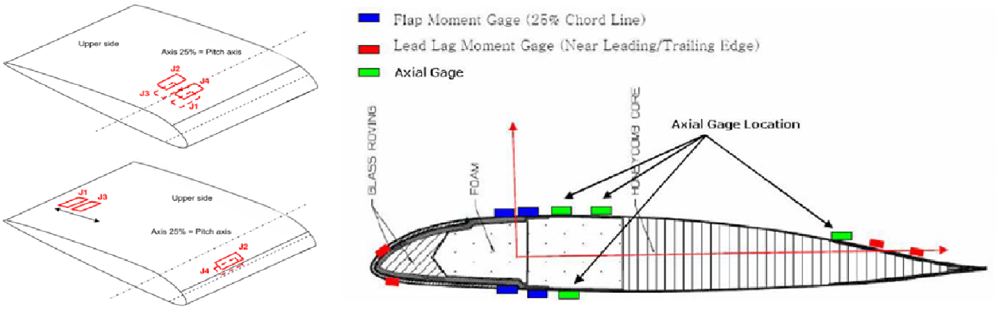

Figure 3. Strain gage location for measuring bending moments

The first step to load calibration is to measure the voltage signal of the bridge circuit by gradually increasing the calibration weight. The second step is to calculate the calibration coefficient in order to convert the voltage signal stored in the bridge circuit to moment values.

5 Conclusions

The S-N fatigue test method was applied to perform the fatigue tests of full scale composite helicopter blades. It was possible to increase the test frequency up to the 4.5~5Hz, and the resonant fatigue test can save time and more efficiently assess the fatigue life compared to existing test method. Also, the S-N curves of each composite material were obtained successfully. An accumulator was connected to the cylinder block of the hydraulic actuator so that it can take on the functions of the hydraulic damper to reduce the dynamic change of centrifugal force caused by blade’s motion. It is expected that this study can be applied to the fatigue evaluation of composite structures with dynamic loads that have a major impact on fatigue life.

Acknowledgements

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