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Input Data from Fatigue Tests and from Vibratory Stress Survey of the Propeller Blades for Probabilistic Assessment

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Abstract: The article is focused on evaluation of the data from fatigue tests and vibratory stress survey of propeller blades. Probability density of fatigue data and loading spectrum from ground and flight operation were analyzed. Safety coefficients required by Civil Aviation Agencies are introduced. Probabilistic assessment based on Monte Carlo method will be the next step in evaluation of the service life with requested probability of hazardous propeller effect.

Keywords: Fatigue Tests; S-N Curve; Strain Gages; Propeller Blade; Safety Coefficients.

1 Introduction

Civil aviation agencies around the world require propeller safety analysis. Part of this analysis is based on fatigue characteristics and steady and vibratory stress loading of the propeller primary structural parts, for example propeller blades. Safety coefficients required by Agencies are introduced to cover unknown variables in fatigue tests and stress surveys. Set of twenty-nine blades with different history were fatigue tested. The all tests were conducted in Avia Company. The each stress level was analyzed in detail and probability density based on log-normal distribution was constructed. Final evaluation of the fatigue data is showed in probability paper.

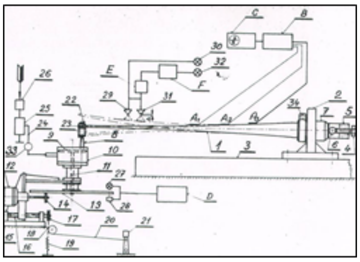
Vibratory stress survey of propeller blades during aircraft ground and flight operation was evaluated by Rain Flow Method and loading spectrum was obtained. Stress survey uses strain gages glued on blades and telemetry equipment manufactured by Telemetrie Elektronik Company. Transmitter with battery pack is installed on the propeller hub by means special aluminum fixture and receiver with data recorder is placed and fixed in the aircraft cabin or cargo space.

2 Fatigue Tests of Propeller Blades

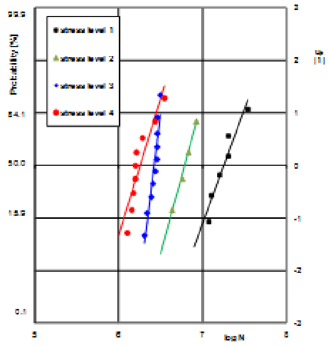
The total twenty-nine propeller blades were tested in fatigue equipment uses pressure air and blade natural frequency of the blade first flatwise. The blade shank was preloaded by screw to obtain conditions of fixed blade. The equipment was designed and manufactured by Avia especially for blade fatigue testing. Stress level and frequency/cycles was measured by glued strain gages on the blades. The new blades, overhauled blades with approved repairs limits, blades after aircraft service operation (thousands of hours) and blades after operation in the test cells (thousands of hours) were used in the fatigue tests. The goal of the tests was also cover conditions of blade service deterioration.

2.1 Experimental Results

The each test stress level was analyzed and probability density curve was constructed. Standard deviations were calculated in each level and were approximated by minimum square method to obtain description of S-N curve with variable standard deviation in extrapolated range up to giga cycle area.



(a) test hardware for fatigue tests



(b) probability paper of selected test levels

Fig. 1: Fatigue test configuration and test results.

3 Vibratory Stress Survey

The Finite Element Analysis is used for harmonic analysis to found the blade natural frequencies and places with maximum stress for each natural shape. Campbell diagram is plotted to find the possible resonance regimes based on intersection between natural shape and excitation frequencies caused by engine type or aircraft configuration or flight regimes. The strain gages (350 Ω, Vishay manufacturer) are glued on the blades profile and shank part and wired to transmitter powered by battery pack which is mounted on the special aluminum fixture fixed on the propeller hub. Wire antenna is fixed on rear bulkhead of the propeller spinner. The second part of wire antenna is fixed on engine cowling near to propeller rear bulkhead and plug into receiver. Receiver with digital data recorder (TEAC manufacturer) is fixed in the aircraft cabin or cargo space. Also receiver and data recorder is powered from battery pack independently on aircraft electricity system. The eight channels/gages are possible to measure and transmit to receiver. The seven channels are wired into quarter-bridge and the last channel is wired into half-bridge for measurement of torsion. Data from typical ground and flight aircraft operation is measured and recorded. Also some special conditions like ground cross wind or in-flight engine shutdown are measured if is required. NI DIAdem software is used for quick review of measured data. Thereafter data from the selected gages and regimes are evaluated by Rain Flow Method and frequency analysis FFT which is the part of own company software package.

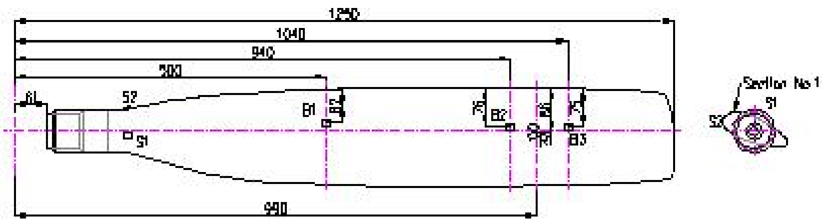


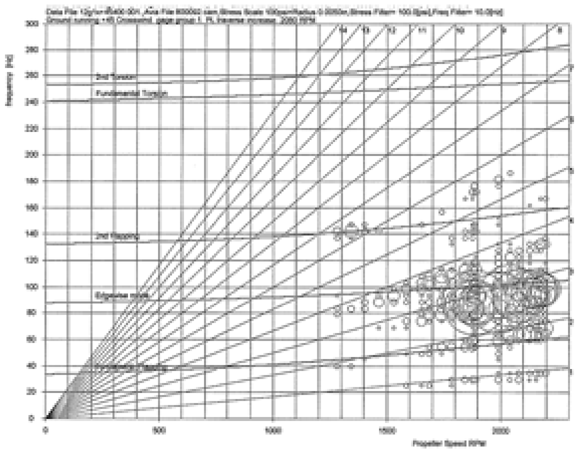
Fig. 2: Example of the strain gages location on the blade.

The evaluated gages and regimes with appropriate stresses and frequencies are written in the tables, histograms and then used for fatigue life calculation.

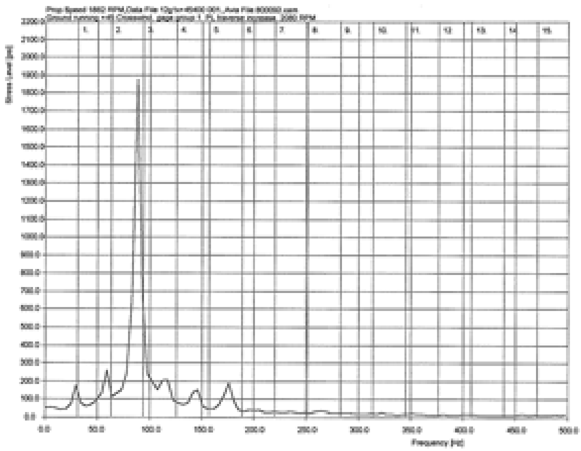
4 Safety Coefficients

Safety coefficients introduced by agencies cover the spread in fatigue characteristics and loads; possible deterioration of fatigue characteristics due to service damage and also fatigue test schedule. The all safety coefficients are used at service life calculation which is based on Palmgren-Miner law. Evaluation of probability of hazardous propeller effects is required.

The first safety coefficient K1 used for multiply of vibratory stress amplitude is based on number of fatigue test specimens and scatter of propeller loading. The second safety coefficient K2 takes into account difference



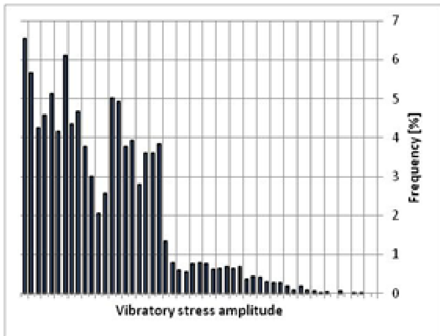
(a) Campbell diagram



(b) frequency analysis of the selected regime

Fig. 3: Example of data evaluation from vibratory stress survey.

(a) telemetry equipment



(b) stress histogram from the flight

Fig. 4: Telemetry equipment and data evaluation from the flight.

between fatigue test schedule and actual loads in service, K2 = 2 when fixed amplitude is used during fatigue test. The last safety coefficient K3 takes into account deterioration of fatigue characteristics due to service damage of the propeller parts. K3 = 3 for usual service conditions. Calculated fatigue life must be divided by the both coefficients K2 and K3.

5 Conclusion

In total, 29 propeller blades manufactured from die forged aluminum alloy were tested. Values of standard deviations on different test levels confirmed high quality of material and general dependence standard deviation on stress level. Data from ground and flight vibratory stress survey was evaluated for each regime and histograms were constructed. Also repeated measurements with the same gage installations and the same operational conditions in ground and flight were analyzed to find scatter of measured data.

Tab. 1: Safety coefficient K1.

number of specimen [-]	1	2	3	4	5	10	15	20	30	40	50	60
K1 [-]	2.22	1.94	1.81	1.74	1.68	1.55	1.48	1.44	1.39	1.35	1.32	1.30

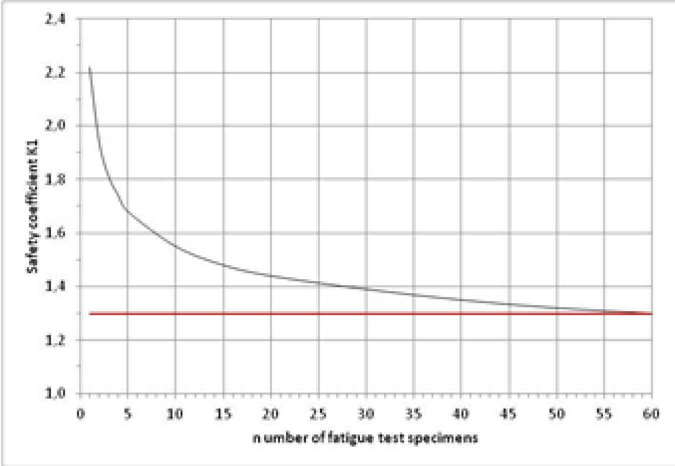


Fig. 5: Safety coefficient K1.

Fatigue characteristics and propeller loading have the random background. These random variables with appropriate distributions can be used for probabilistic modeling to obtain probabilistic assessment of hazardous propeller effects.

Acknowledgement

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