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Analysis of middle bearing failure in rotor jet engine using tip-timing and tip-clearance techniques

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ABSTRACT

The reported problem is the failure of the middle bearing in an aircraft rotor engine. Tip-timing and tip-clearance and variance analyses are carried out on a compressor rotor blade in the seventh stage above the middle bearing. The experimental analyses concern both an aircraft engine with a middle bearing in good working order and an engine with a damaged middle bearing. A numerical analysis of seventh stage blade free vibration is conducted to explain the experimental results. This appears to be an effective method of predicting middle bearing failure. The results show that variance first increases in the initial stages of bearing failure, but then starts to decrease and stabilize, and then again decrease shortly before complete bearing failure.

1. Introduction

Rolling element bearings are one of the most essential parts in rotating machinery. During operation, bearings are often subjected to high loading and difficult working conditions, which in turn often lead to the development of defects on the bearing components [1]. One way to increase operational reliability is to monitor incipient faults in these bearings [2–4]. Analytical models for predicting the vibration frequencies of rolling bearings and the amplitudes of significant frequencies with localized defects in bearings have been proposed in [5–7].

FFT is one of the widely used fault detection techniques [8,9]. The only drawback is that it is not suitable for non-stationary signals. In recent years, a new time frequency analysis technique, called Wavelet Analysis, was developed. The advantage of Wavelet Analysis is that the non-stationary characteristic of a signal can be easily highlighted in its spectrum [8–12]. Tip-timing and tip-clearance can be used for analysis of bearing failure.

The tip-timing technique was developed by a number of different organizations over the past 88 years to measure rotor blade vibration:

1924 - Campbell [13] applied induction sensors to identify the natural frequencies of rotating steam turbine blades.
1949 – Hardigg [14] patented apparatus for measuring rotor blade vibration.
1956 – Warnick [15] patented the “Capacitance Probe” for measuring turbine blade vibrations at higher temperatures.

Abbreviations: FE, Finite element; BTT, Blade Tip Timing; VAR, Variance; EO, Engine Order; A_i, ith blade amplitude; f_i, frequency of blade vibration; f_{oi}, aliasing frequency of blade vibration; f_r, rotation blade frequency; x_{ik}, measured signal of ith blade by sensor number k; t_s, time of blade rotation (time of sampling); n, number of blade rotation; ϕ_I, phase angle of the ith blade; φ_{ij}, angle between sensor i and j

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1958 – Shapiro [16] patented a vibration detector and measuring instrument for compressor blade vibrations.

1964 - Zablotskiy et al. described a non-contact device for blade vibration measurement [17]. Holz [18] patented a tip-timing blade measurement method.

1967 – Hohenberg [19] conducted experimental analyses using the lycoming blade vibration detector developed at Avco Lycoming.

1969 - Kulczyk et al. [20] developed a laser Doppler instrument for measuring turbine blade vibration.

1970 – Robinson [21] patented a system for measuring rotor vibration. Zablotskiy and Korostelev [22] performed an integral vibration analysis using the ELURA device and used inductive sensors (known also as speed pickups or Variable Reluctance sensors) for blade tip-timing in steam turbines.

1976 – Stargardter [23] developed a system to detect static deflection and flutter on a bladed disk.

1977 - USAF and NASA implemented stroboscopic imagery and photoelectric scanning techniques to observe blade flutter [24]. Roth [25] presented the method of non-contact vibration using the optical sensor.

1980 - an NSMS prototype (1st generation) with a stress conversion algorithm was experimentally verified at AEDC [26] (Arnold Engineering Development Center). Roth [27] presented results of vibration measurements on rotating turbine rotor blades using optical probes.

1985 - AEDC began developing a full-scale system to measure integral and non-integral vibration [28] (2nd generation NSMS).

1987 - Pratt & Whitney and United Technology developed a near-real–time non-integral NSMS system [29]. Szczepanik and Kudelski [30,31] developed and installed the SAD-2 system (1st generation) into the first stage compressor of an SO-3 TS-11 *Iskra* jet engine. This was one of the first airborne tip-timing systems in the world and is still used by the Polish Air Force today.

1989 - Kudelski and Szczepanik [32] demonstrated the ability of NSMS to detect rotor blade crack growth.

1992 - the 3rd generation NSMS system was developed which was able to measure multiple simultaneous modes [33,34].

1993 - the SNDŁ-1b/SPŁ-2b diagnosing system was developed for SO-3 engines [35–37].

1996 - PIWG proposed the current 4th generation NSMS system [21] . Heath and Imregun [38] presented a tip-timing system for turbo machinery using optical probes.

1997 - Zielinski and Ziller [39] presented optical blade vibration measurements at MTU.

1999 - NASA developed [40,41] new tip-clearance and 2-D leading edge/trailing edge NSMS probes.

2000 - Kurkov and Dhadwal [42] demonstrated the capability of NSMS to detect blade and hub crack growth. Boriszanskij [43] presented a tip-timing system for shrouded bladed discs in steam turbines. Heath [44] presented a new technique for identifying synchronous resonances using tip-timing. Zielinski and Ziller [45] showed non-contact vibration

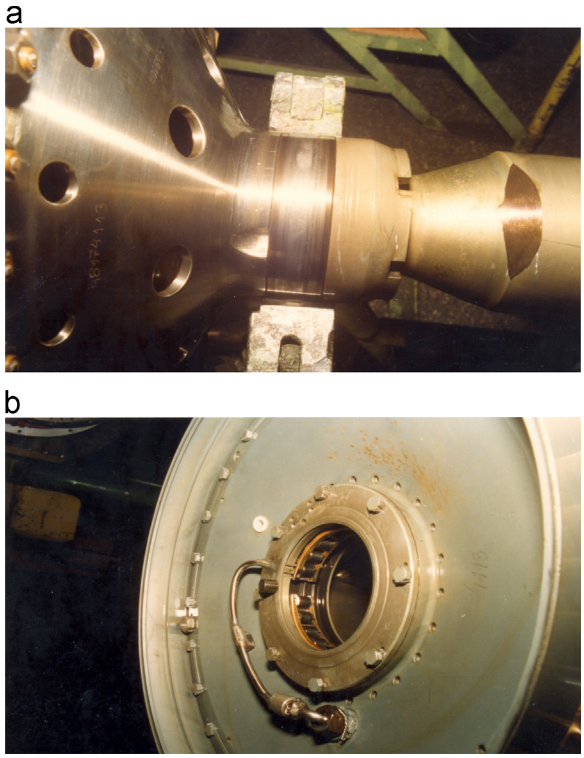

Fig. 1. (a) The inner running track of the aircraft engine middle bearing. (b) Damaged elements of the aircraft engine middle bearing.

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